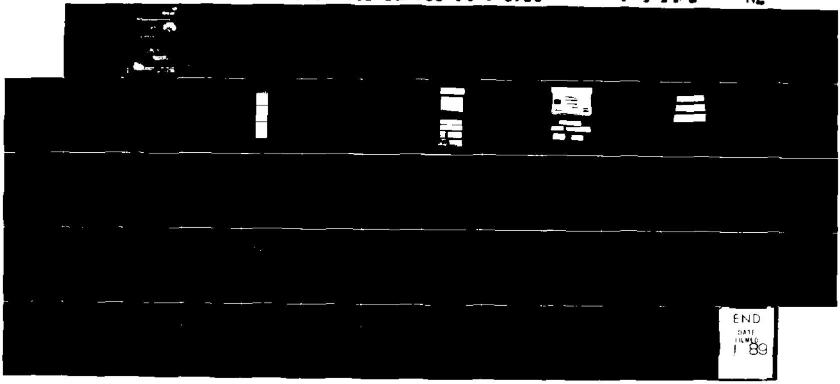
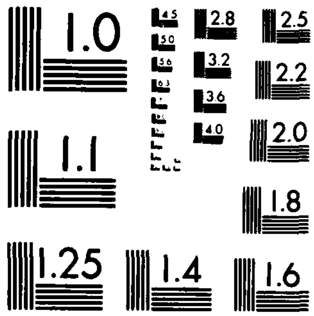
AD-A186 340 THROUGH-TRANSMISSION/PULSE-ECHO ULTRASONIC EQUIPMENT 1/1
EVALUATION(U) NONDESTRUCTIVE TESTING INFORMATION
ANALYSIS CENTER SAN ANTONIO TX H KWUN 26 SEP 87
UNCLASSIFIED SAALC/MME I-87-001 DLA900-84-C-0910 F/G 14/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

AD-A186 340

[illegible] Analysis Center
[illegible]

Prepared for

[illegible] Program Office
[illegible]
[illegible] Engineering Inspection
[illegible]
[illegible]

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

ADA186340

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release Distribution Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 17-7958-834	5. MONITORING ORGANIZATION REPORT NUMBER(S) MMEI-87-001
6a. NAME OF PERFORMING ORGANIZATION Southwest Research Institute — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION MMEI/SA-ALC, Kelly Air Force Base
6c. ADDRESS (City, State, and ZIP Code) 6220 Culebra Road San Antonio, Texas 78284	7b. ADDRESS (City, State, and ZIP Code) San Antonio, Texas 78241
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Defense Logistics Agency — 8b. OFFICE SYMBOL (If applicable) DTIC-DS	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DLA 900-84-C-0910, CLIN0001BC
8c. ADDRESS (City, State, and ZIP Code) DTIC, Cameron Station Alexandria, Virginia 22314	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Through-Transmission/Pulse-Echo Ultrasonic Equipment Evaluation

12. PERSONAL AUTHOR(S) Hegeon Kwun

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 9/27/86 TO 9/26/87	1987, September 26	57

16. SUPPLEMENTARY NOTATION
Performed as a Special Task for the Nondestructive Testing Information Analysis Center

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A literature search was conducted to identify commercially available ultrasonic equipment for nondestructive inspection of bonded structures used in advanced high performance aircraft for flaws such as delaminations, debonds, and impact damage. More than fifty instruments were identified from the search. The majority (approximately 80 percent) of the instruments were conventional ultrasonic flaw detectors based on the pulse-echo/through-transmission techniques. A small fraction (approximately 20 percent) of the instruments are based on other techniques such as resonance, acousto-ultrasonic, and so-called shadow techniques.

Approximately forty instruments were evaluated, based on the data available from the literature, for their capabilities and limitations. A trend toward the digital, automatic, and computer-controlled instruments was observed. The majority of the commercial instruments are microprocessor-controlled with interfaces for communication with other devices

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Ms. Susan Frisch	22b. TELEPHONE (Include Area Code) (512) 925-6408 — 22c. OFFICE SYMBOL SA-ALC/MMEI

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. ABSTRACT (Continued)

such as an external computer, a printer, a recorder, or a video display. Also, the majority of the instruments are modular in construction to facilitate maintenance and repair. In addition, almost all instruments are equipped with visual and/or audible alarms.

Most of the instruments use sensors (or probes) which require a liquid couplant such as light machine oil or water to transmit ultrasonic energy through the contacting interfaces between the probe and the part under inspection. Several instruments are operated with dry-coupled probes which do not require a liquid couplant. The dry-coupled probes use a pliable and resilient material such as rubber to transfer ultrasonic energy from the piezoelectric crystal to the part under inspection and vice versa. Almost all of the instruments require a smooth and clean surface of the part for inspection. However, substantial surface preparation such as removing paint on the part is not generally required. In addition, most of the instruments are operable in field environmental conditions. Except for highly sophisticated and automatic instruments and some instruments operated with a wheel-type probe, the inspection speed of the instruments is generally slow. Most of the instruments are portable. Also, about 50 percent of the instruments are battery powered. The operating time of the batteries typically ranges from 6 to 12 hours. The equipment cost varies over a wide range from several thousand dollars to over a quarter of a million dollars depending on the degree of sophistication and automation.

Four instruments were selected for laboratory evaluation. They were NDT Instrument Inc.'s BondaScope 2100, Acoustic Emission Technology Corp.'s Model 206 AU instrument, Sonatest's UFD-S instrument, and Fokker B.V.'s Bondtester Model 80L. A total of 28 reference bonded structure samples containing a total of 213 reference flaws were used in the evaluation. The samples represented a wide variety of bonded structures including metal-metal, metal-composite, composite laminates, metal-honeycomb-metal, and composite-honeycomb-composite structures. In general, three of the four instruments showed good flaw detectability in most of the structures investigated, while the remaining one showed good flaw detectability on only a limited number of samples. Two of the four instruments which exhibited better performance were recommended for use in inspection of bonded aircraft structures.

THROUGH-TRANSMISSION/PULSE-ECHO ULTRASONIC EQUIPMENT EVALUATION

FINAL REPORT
SwRI Project 17-7958-834

Performed as a special task for
Nondestructive Testing Information Analysis Center
under Contract No. DLA 900-84-C-0910, CLIN 0001BC

Prepared for

Nondestructive Inspection Program Office
Service Engineering Division
Directorate of Material Management and Engineering Inspection
San Antonio Air Logistics Center
Kelly Air Force Base, Texas 78241

September 1987

Written by

Hegeon Kwun

Hegeon Kwun
Senior Research Scientist
Department of Nondestructive
Science and Research

Approved by

Amos E. Holt

Amos E. Holt
Vice President
Nondestructive Evaluation Science
and Technology

FOREWORD

This work was conducted under a program sponsored by Directorate of Material Management and Engineering Inspection (MMEI), San Antonio Air Logistics Center (SA-ALC), Kelly Air Force Base, San Antonio, Texas. The author experesses his special appreciation to Mr. John Petru, Chief Engineer, and Ms. Susan Frisch, Engineer, of Nondestructive Inspection Program Office, Service Engineering Division, MMEI/SA-ALC, for their participation and guidance in this program and their assistance in obtaining the reference bonded structure samples used in the laboratory evaluation of ultrasonic bond testing equipment. The author also thanks the following individuals for their courtesies and cooperation in arranging and providing the instruments for the laboratory evaluation: Mr. Ronald J. Botsco of NDT Instruments Inc., Mr. Jim Rhamey of Automation/ Sperry, Qualcorp, Mr. Paul Slaba of NDT Technologies U.S., Inc., Mr. Jerry Slaba of NDT Technologies Inc., Mr. Gordon Turner of NDT Equipment and Supply Inc., and Mr. Gordon Schneider of Acoustic Emission Technology Corp. Particular thanks go to Mr. Jerry Slaba for his time and effort in demonstrating and evaluating the UFD-S instrument at Southwest Research Institute. Appreciation also goes to all the companies who provided technical information on their respective bond testing ultrasonic equipment. The author also thanks Mr. David Alcazar of SwRI for his assistance in conducting the program.

SUMMARY

A literature search was conducted to identify commercially available ultrasonic equipment for nondestructive inspection of bonded structures used in advanced high performance aircraft for flaws such as delaminations, debonds, and impact damage. More than fifty instruments were identified from the search. The majority (approximately 80%) of the instruments were conventional ultrasonic flaw detectors based on the pulse-echo/through-transmission techniques. A small fraction (approximately 20%) of the instruments was based on other techniques such as resonance, acousto-ultrasonic, and so-called shadow techniques.

Approximately forty instruments were evaluated, based on the data available from the literature, for their capabilities and limitations. A trend toward the digital, automatic, and computer-controlled instruments was observed. The majority of the commercial instruments are microprocessor-controlled with interfaces for communication with other devices such as an external computer, a printer, a recorder, or a video display. Also the majority of the instruments are modular in construction to facilitate maintenance and repair. In addition, almost all instruments are equipped with visual and/or audible alarms.

Most of the instruments use sensors (or probes) which require a liquid couplant such as light machine oil or water to transmit ultrasonic energy through the contacting interfaces between the probe and the part under inspection. Several instruments are operated with dry-coupled probes which do not require a liquid couplant. The dry-coupled probes use a pliable and resilient material such as rubber to transfer ultrasonic energy from the piezoelectric crystal to the part under inspection and vice versa. Almost all the instruments require a smooth and clean surface of the part for inspection. However, substantial surface preparation such as removing paint on the part is not generally required. In addition, most of the instruments are operable in field environmental conditions. Except for highly sophisticated and automatic instruments and some instruments operated with a wheel type probe, the inspection speed of the instruments is generally slow. Most of the instruments are portable. Also about 50% of the instruments are battery powered. The operating time of the batteries typically ranges from 6 to 12 hours. The equipment cost varies over a wide range from several thousand dollars to over a quater of million dollars depending on the degree of sophistication and automation.

Four instruments were selected for laboratory evaluation. They were NDT Instrument Inc.'s BondaScope 2100, Acoustic Emission Technology Corp.'s Model 206 AU instrument, Sonatest's UFD-S instrument, and Fokker B.V.'s Bondtester Model 80L. A total of 28 reference bonded structure samples containing a total of 213 reference flaws were used in the evaluation. The samples represented a wide variety of bonded structures including metal-metal, metal-composite, composite laminates, metal-honeycomb-metal, and composite-honeycomb-composite structures. In general, three of the four instruments showed good flaw detectibility in most of the structures investigated, while the remaining one showed good flaw detectability on only a limited number of samples. Two of the four instruments which exhibited better performance were recommended for use in inspection of bonded aircraft structures.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS AND TABLES

I. INTRODUCTION

A. Background

Adhesive bonding is widely used in the construction of advanced high performance aircraft utilizing metal-to-metal, metal-to-composite, honey-comb, and multilayered composite structures. The main reason for this widespread use is because it provides more uniform stress transfer, increased fatigue life, and reduced weight than structures joined by traditional fastening techniques such as welding and riveting. Presently, adhesively bonded components are found not only in secondary structural applications, but also in highly loaded, primary structures.

To determine the structural integrity and reliability of adhesively bonded components, it is essential to nondestructively inspect the parts for voids, disbonds, delaminations, and/or damage. Ultrasonic methods including through-transmission, pulse-echo, and resonance techniques are used extensively in the Air Force for the inspection of bonded and multilayered aircraft structures. Presently, a wide variety of ultrasonic instruments is commercially available for inspection of bonded structures. Information on the types of ultrasonic instruments available on the market and their respective capabilities and limitations is important for the Air Force to assess the current state-of-the-art of the instrument technology and thus to determine the Air Force's future equipment needs to improve the accuracy and reliability of nondestructive inspection.

B. Objectives

The objectives of the project were to:

(1) Identify various commercially available ultrasonic equipment for detecting defects such as disbonds, delaminations, and subsurface damage in bonded aircraft structures.

(2) Evaluate the capabilities and limitations of the identified equipment based on data available from literature and, for a limited number of selected instruments, experimentally evaluate their capabilities in the laboratory by using reference samples of bonded aircraft structures.

II. LITERATURE SURVEY AND EVALUATION OF ULTRASONIC INSTRUMENTS FOR INSPECTION OF BONDED AIRCRAFT STRUCTURES

A literature survey was conducted to identify ultrasonic equipment for nondestructive testing (NDT) of bonded structures. The computer retrieval facility at the Nondestructive Testing Information Analysis Center (NTIAC) at SwRI and manual searches of product catalogues, product briefings and recent issues of trade magazines and NDT related journals were used. The search was limited mostly to those instruments available domestically. From this search, names of more than fifty ultrasonic bond testing instruments and the respective manufacturers were identified, as listed in Appendix A. Most of the instruments listed in Appendix A represent the most recent models. Many old models were intentionally excluded from the list. The list, therefore, was not meant to be an exhaustive one. The majority of the instruments were conventional ultrasonic flaw detectors based on the pulse-echo and/or through-transmission techniques. The instruments based on different techniques such as resonance or acousto-ultrasonics (combination of acoustic emission and ultrasonics) comprised a small minority.

Through a written communication to, and a direct phone contact with, the manufacturer or a dealer of each identified instrument, the technical and price information on the equipment was requested. While gathering the information, the list of the identified instruments was reviewed by personnel of SA-ALC/MMEI at Kelly Air Force Base at a meeting held in Feb. 1987. After the review, approximately forty instruments were chosen for literature evaluation excluding those whose capabilities were well known to SA-ALC/MMEI personnel and/or those systems that were unsuitable for field inspection.

Based on the data available in the literature gathered, the chosen instruments were evaluated by using the evaluation form and rating guidelines described in Appendix B. Because of inadequate information, some of the factors, particularly accuracy, sensitivity, repeatibility, and reliability, were difficult to evaluate. Consequently, in many cases, subjective judgement was used for evaluation. The evaluation was therefore more qualitative than quantitative and, in some cases, was incomplete. Thus, no attempts were made to rank the instruments. The literature evaluation data were submitted to SA-ALC/ MMEI separately, and the overall findings may be summarized as described in Table 1. Accuracy and sensitivity were not included in Table 1 because of insufficient information.

The majority (32 out of 41) of the evaluated instruments were based on the conventional pulse-echo/through-transmission techniques. Of the remaining non-conventional ultrasonic instruments (9 out of 41), six were based on resonance techniques, two on the acousto-ultrasonic technique, and one on the shadow technique (see Section III.A.3). All the instruments required some degree of operator skill and experience, particularly in the interpretation of the detected signals.

Most of the instruments (33 out of 41) used sensors (or probes) which require a liquid couplant such as light machine oil or water to transmit ultrasonic energy through the contacting interfaces between the probe and the part under inspection. Several instruments (8 out of 41) were operated with dry-coupled

Table 1

SUMMARY OF LITERATURE EVALUATION OF ULTRASONIC IN
INSPECTION OF BONDED STRUC

	Instrument	Technique	Operation Skill Setup	Proc.	Interp.	Need for Liquid Couplant	Need for Surface Preparation	Sensitivity to Environment	Inspection Speed	Repeatabi
1.	Ultra Image III	PE/TT[1]	High	High	Low	Yes	Mod	Low	High	High
2.	Acous.-Ultrasonic Instru. Sys.	AU[2]	High	High	High	Yes	Mod	Mod	Low	Low
3.	Multisonic/PC	PE/TT	High	High	Low	Yes	Mod	Mod	High	High
4.	UFD-S	Shadow	Low	Low	Low	No	Low	Low	Mod	Mod
5.	ZIPSCAN 2	PE/TT	High	High	Low	Yes	Mod	Low-Mod	High	High
6.	TTU-90	PE/TT	Low	Low	Mod	No	Low	Low	Mod	Mod
7.	USIP 12	PE/TT	Mod	Mod	Mod	Yew	Mod	Low	Low	Mod
8.	USIP 11	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
9.	PARIS	PE/TT	High	High	Mod	No	Mod	Low	High	High
10.	Sigima Series 2000	PE/TT	High	High	Mod	Yes	Mod	Mod	High	High
11.	USD-1	PE/TT	High	High	Mod	Yes	Mod	Low-Mod	Low	High
12.	Fokker Bondtester Model 80L	Reson.	Low	Low	Mod	Yes	Mod	Low	Low	Mod
13.	Metrotek M-Series	PE/TT	Low	Mod	Mod	Yes	Mod	Low	Low	Mod
14.	NDT 132	PE/TT	Low	Mod	Mod	Yes	Mod	Low	Low	Mod
15.	AET 206AU	AU	Mod	Mod	High	No	Low	Low	Mod	Mod
16.	NovaScope 3000	PE/TT	Low	Low	Low	Yes	Mod	Low	Low	Mod
17.	NovaScope[3]	PE/TT	Low	Low	Low	Yes	Mod	Low	Low	Mod
18.	BondaScope 2100	Reson.	Low	Low	Mod	Yes	Mod	Low	Low	Mod
19.	210 Bondtester	Reson.	Low	Low	Mod	No	Mod	Low	Low	Mod
20.	S-1A Sondicator[3]	Reson.	Low	Low	Mod	No	Mod	Low	Low	Mod
21.	S-2B Sondicator	Reson.	Low	Low	Mod	No	Mod	Low	Low	Mod
22.	PS-710B	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
23.	DZ-3	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Low
24.	FX-5	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
25.	FX-7	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
26.	Echograph 1150	PE/TT	High	High	Low	Yes	Mod	Low	High	High
27.	Echograph 1030	PE/TT	High	High	Mod	Yes	Mod	Low	Low	High
28.	Echograph 1030-QUASCO	PE/TT	Mod	Mod	Low	Yes	Mod	Low	Low	High
29.	Echograph Series 10	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
30.	Echograph Series 20	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
31.	NovaScope 412	PE/TT	Mod	Mod	Mod	Yes	Mod	Low	Low	Mod
32.	Epoch 2002	PE/TT	Mod	High	Mod	Yes	Mod	Low	Low	High
33.	5052 UA	PE/TT	Low	Low	Mod	Yes	Mod	Mod	Low	Low
34.	5055 UA	PE/TT	Low	Low	Mod	Yes	Mod	Mod	Low	Low
35.	Teneleven SG	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
36.	PA 1020	PE/TT	Mod	Mod	Mod	Yes	Mod	Low	Low	Mod
37.	MIA 3000	Reson.	High	High	Mod	No	Mod	Low	Mod	Mod
38.	USL 33	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Mod
39.	USL 48	PE/TT	Mod	Mod	Mod	Yes	Mod	Low	Low	Mod
40.	USM 3	PE/TT	Low	Low	Mod	Yes	Mod	Low	Low	Low
41.	USM 35	PE/TT	Mod	Mod	Mod	Yes	Mod	Low	Low	Mod

(1) Pulse-Echo/Through-Transmission

(2) Acoustic-Ultrasonic

(3) Discontinued Production

1 of 2

STRUMENTS FOR NONDESTRUCTIVE
TURES

lity	Recorder Interface Availability	Portability	Power Rqmt.	Maintainability	Equipment Cost	Personal Safety	Ability to Automate
	High	Mod	High	Mod-Low	High	High	Automated
	Mod	Mod	High	Mod-Low	High	High	High
	High	Low	High	Mod-Low	High	High	Automated
	Mod	High	Low	Mod	Mod	High	Low
	High	Mod	High	Mod-Low	High	High	Automated
	Mod	High	Mod	Mod	Low	High	Mod
	Mod	Mod	Mod	Mod	Mod	High	Mod
	Mod	High	Mod	Mod	Low	High	Low
	High	Mod	High	Mod-Low	High	High	Automated
	High	Low	High	Mod-Low	High	High	Automated
	High	Mod	High	Mod-Low	High	High	Automated
	Mod	High	Low	Mod	Mod	High	High
	Mod	High	Mod	High-Mod	Mod	High	Mod
	Mod	High	Low	High-Mod	Low	High	Mod
	Mod	High	Low	High-Mod	Mod	High	Mod
	Mod	High	Low	Mod	Low	High	Mod
	Mod	High	Mod	Mod	Low	High	Mod
	Mod	High	Mod	Mod	Mod	High	High
	Mod	High	Low	Mod	Low	High	Mod
	Mod	High	Mod	Mod	Mod	High	Mod
	Low	High	Low	Mod	Low	High	Low
	Mod	High	Low	High-Mod	Low	High	Mod
	Low	High	Low	Mod	Low	High	Low
	Mod	High	Low	Mod	Low	High	Mod
	Mod	High	Low	Mod	Low	High	Mod
	Mod	Mod	High	Mod-Low	High	High	Automated
	Mod	Mod	Low	Mod-Low	Mod	High	High
	Mod	High	Low	Mod	Mod	High	High
	Mod	High	Low	Mod	Low	High	Mod
	Mod	High	Low	Mod	Low	High	Mod
	Mod	Mod	Mod	Mod	Low	High	High
	Mod	High	Low	Mod	Low	High	High
	Mod	High	Mod	Mod	Low	High	Mod
	Mod	High	Mod	Mod	Low	High	Mod
	Mod	High	Low	Mod	Low	High	Low
	Mod	Mod	Low	Mod	Mod	High	Mod
	Mod	Mod	Low	Mod		High	High
	Mod	High	Low	Mod	Low	High	Low
	Mod	High	Low	Mod	Low	High	Mod
	Low	High	Low	Mod	Low	High	Low
	Mod	High	Low	Mod	Low	High	Mod

2 of 2

probes which do not require a liquid couplant. The dry-coupled probes use a pliable and resilient material such as rubber to transfer ultrasonic energy from the piezoelectric crystal to the part under inspection and vice versa. The coupling state of both the liquid-coupled and dry-coupled probes influences the inspection results. Therefore, to obtain repeatable results, uniform and consistent coupling of the probes is required.

Almost all the instruments evaluated required a smooth and clean surface of the part for inspection. However, substantial surface preparation such as removing paint on the part is not generally required. In addition, most of the instruments were operable in field environmental conditions. Except for highly sophisticated and automatic instruments and some instruments operated with a wheel-type probe, the inspection speed of the instruments was slow.

With the recent advancements in semiconductor and computer technologies, ultrasonic NDT instruments have been undergoing a transition from analog and manual types to digital, automatic, and computer-controlled types. Most of the instruments for which information was gathered incorporated the recent, state-of-the-art electronic design technologies partially or totally. At present, almost all instruments are equipped with visual and/or audible alarm to aid in flaw detection. The majority of the instruments are modular in construction to facilitate maintenance and repair. Also, the majority of the instruments are microprocessor-controlled and have interfaces for communication with an external computer and peripheral devices such as a printer, a video display, or a data storage device. Some of the computer-controlled instrumentation systems have capabilities for data acquisition, data processing, data analysis and evaluation, as well as documentation of the inspection. In general, microprocessor or computer-controlled instruments require a fair amount of operator training (2 weeks or more).

Portability of the instruments evaluated was generally high. Also, about half of the instruments (23 out of 41) were battery operable (Low in the Power Requirement column in Table 1). The operating time of the batteries varied with each instrument but ranged typically from 6 to 12 hours.

The detailed literature evaluation data submitted separately were reviewed by personnel of SA-ALC/MMEI at Kelly Air Force Base. Upon review, the following four instruments were selected for further experimental evaluation in the laboratory:

(1) NDT Instrument Inc.'s BondaScope 2100
(2) Acoustic Emission Technology Corp.'s Model 206 AU instrument
(3) Sonatest's UFD-S instrument
(4) Fokker B.V.'s Bondtester Model 80 L

Conventional pulse-echo/through-transmission ultrasonic flaw detectors were excluded from the laboratory evaluation because their capabilities are generally well known to the Air Force. Automated and computerized instrumentation systems were also excluded because evaluating such systems in the laboratory was beyond the funding constraint of the program due to a lack of easy access to (or availability of) such systems and a long training time required for operating such systems.

III. LABORATORY EVALUATION OF SELECTED INSTRUMENTS

A. Equipment

1. BondaScope 2100

The BondaScope 2100 instrument operates on an ultrasonic principle, whereby the specific acoustic impedance of the material under test is monitored by electrical circuits sensitive to both the amplitude and the phase of the acoustic impedance. A piezoelectric transducer (or probe) is employed to transmit and receive the ultrasonic energy. The probe is excited by using a continuous wave (CW) of frequency equal to the resonant frequency of the piezoelectric crystal in the probe. Anomalies in the material such as debonds, delaminations, and voids create acoustic impedance changes which are detected, processed, and displayed as a "flying" dot on the instrument CRT.

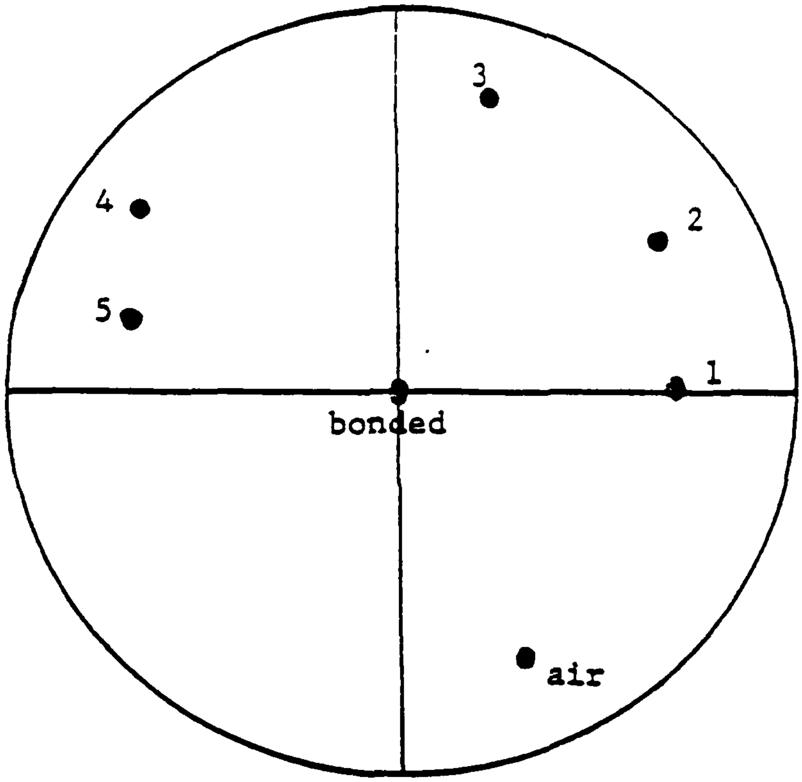
When in use, the instrument is first calibrated or balanced on defect-free material. This calibration positions the dot at the center of the CRT screen. As the probe scans the test piece, the dot will displace from the center of the CRT when anomalies are encountered. The amount of displacement correlates with the changes in the amplitude and phase of the acoustic impedance of the material at that location. Figure 1 illustrates an example of the dot display obtained from a sample of multi-layered bonded laminate with unbonds (from the operating manual of the instrument). In this example, the dot was displaced from the center and moved counterclockwise with the increasing depth of the unbond from the surface of the sample. The position of the dot on the CRT display is used for flaw detection as well as its characterization.

The instrument is operated with a contact type probe which requires a liquid couplant such as light machine oil on the test surface to transmit the ultrasonic energy through the contacting interfaces.

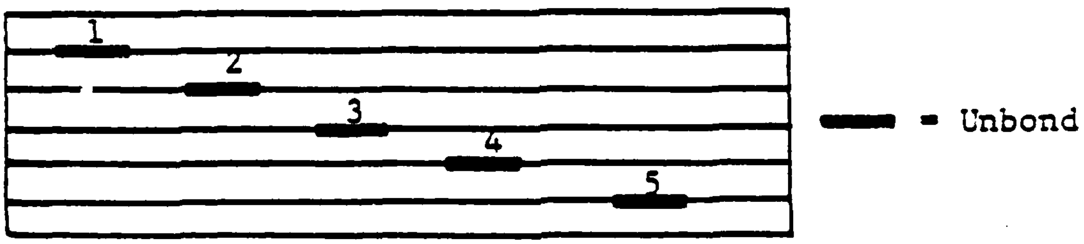
2. Acoustic Emission Technology Corporation Model 206 AU

The Model 206 AU (acousto-ultrasonic) instrument is based on a NASA-developed technique relating the transmission of acoustic waves to the strength of composite material (Ref: A. Vary and R. F. Lark, "Correlation of Fiber Composite Tensile Strength with the Ultrasonic Stress Wave Factor," Journal of Testing and Evaluation, Vol. 7, No. 4, July 1979, pp. 185-191). The method is similar to the ultrasonic pitch-catch technique except that the transmitted sound beam is received by a sensitive, wideband, acoustic emission (AE) type sensor. The instrument in effect simulates an AE event in the material and receives the signal at some distance from the point of source (or injection). The received signal contains information about the wave path of the signal in the material and a parameter called "stress-wave factor" is correlated to the strength of the material or the presence of a defect.

The instrument is operated with wheel-type probes which do not require a liquid couplant. The rubber O-ring or tire on the probe allows transmission of signals from the crystal to the part or vice versa without the application of couplant.



(a) BondaScope Display of Unbonds in Laminate Shown Below



(b) Multi-layered Bonded Laminate with Unbonds

Figure 1. BondaScope Ultrasonic Impedance Plane Presentation for a Multi-layered Laminate

3. UFD-S Instrument

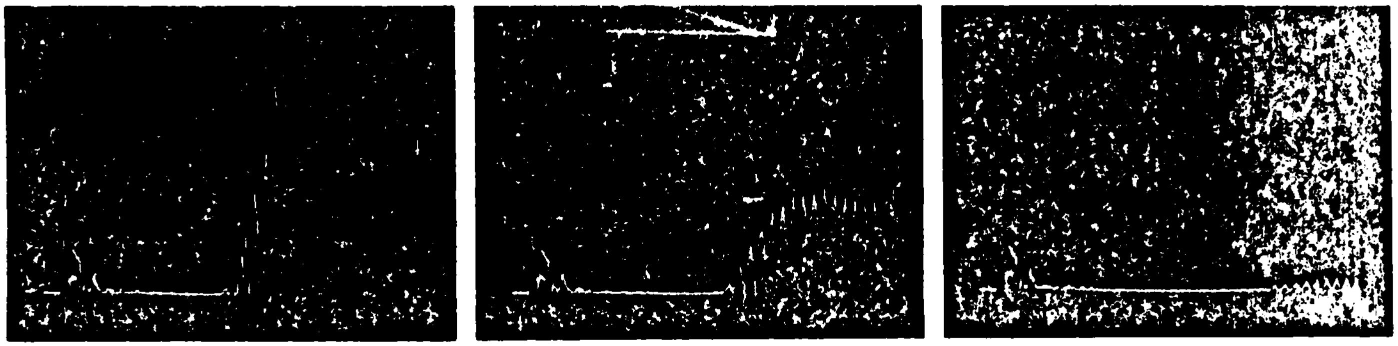
The UFD-S (ultrasonic flaw detector - shadow) instrument uses the shadow technique for flaw detection. The technique is similar to the ultrasonic pulse- echo or pitch-catch method except that it relies on the ultrasonic signal re- directed by the presence of a defect rather than the direct reflected signal for flaw detection. Changes in the pattern of the received signal caused by defects are correlated to the condition of the material under test. More specifically, the following three factors are used for determining the material condition: (1) amplitude of the received signal, (2) displacement of the starting point of the first half-cycle of the received signal on the time base, and (3) shape of the interference pattern. Calibration of the instrument and probe alignment (distance between the transmitter and the receiver and their respective angle relative to the surface of a part under inspection) by using a reference sample of known condition is required prior to the inspection. Any changes in the signal pattern exceeding the predetermined acceptance level would indicate a fault or flawed condition. Figure 2 shows an example of signal pattern change with increasing fault condition (from the instrument brochure). Figure 2a is the signal from a good area. The received signal shown in Figure 2b is shifted to the right and is smaller in amplitude because of a fault condition (no specifics were given on the fault condition in the brochure). As the fault condition becomes more severe, the signal is shifted further to the right accompanied by a further reduction in amplitude as shown in Figure 2c.

Two types of dry coupled probes are used with the instrument: a roller probe and a rubber-tip probe. Both probes do not require any liquid couplant. The roller probe is for continuous scanning. The rubber-tip probe is for intermittent spot checking.

4. Fokker Bondtester Model 80 L

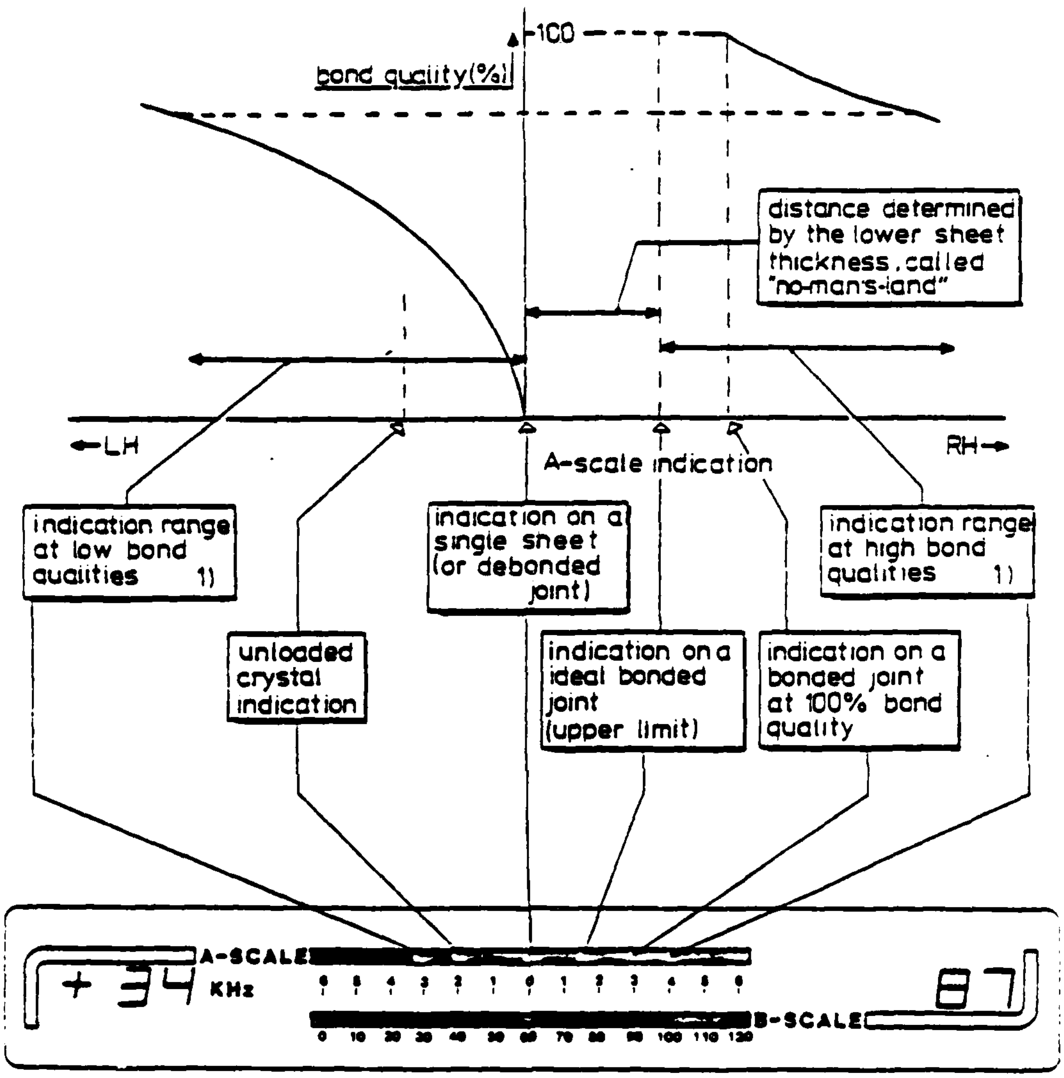
The Fokker Bondtester instrument is based on the principle that the resonant frequency and the electrical impedance of a piezoelectric crystal placed on the surface of a bonded structure are dependent on the quality of the bonded joints. The shift in resonant frequency and the change in electrical impedance of the crystal are measured and used for flaw detection and characterization. The instrument uses a continuous wave (CW) signal like the Bonda-Scope 2100 described above. To find the resonant frequency, however, the frequency of the CW signal is swept in a certain range determined by the setting on the instrument. When the applied CW frequency equals the resonant frequency of the crystal, the electrical impedance of the crystal exhibits the most change. Both the shift in resonant frequency (called A-Scale) and the peak change in electrical impedance (called B-Scale) are displayed on the instrument. Since the instrument relies on relative changes, it must be calibrated prior to the inspection by using a reference sample. An example of typical A-Scale indications for various bond qualities is illustrated in Figure 3 (from the operating manual of the instrument).

The crystals (or probes) used with the instrument require a liquid couplant.



(a) Good Area (b) Faulted Area (c) More Faulted Area

Figure 2. Example of Changes in the UFD-S Signal Pattern With Increasing Fault Condition



1) Only one arbitrary LED-bar indication is shown.

Figure 3. Typical Bondtester A-Scale Indications on a Single Bondline Configuration with Relatively Thin Lower Sheets as a Function of the Bond Quality

B. Specimens

In the laboratory evaluation, three sets of reference bonded samples were used. They were F-16 bonded structure samples manufactured by General Dynamics, F-5 honeycomb structure samples manufactured by Northrop, and graphite/epoxy samples manufactured by Lockheed-Georgia Company. The three reference sample sets consisted of a total of 28 specimens containing a total of 213 reference defects. Further details of the specimens are given below.

1. F-16 Bonded Structure Samples.

The F-16 bonded structure kit consisted of 9 samples representing a wide variety of bonded structures including metal-to-metal, metal-to-composite, composite laminates, metal-honeycomb-metal, and composite-honeycomb-composite structures, and a wide range of thicknesses for each structure type. A photograph of the samples is shown in Figure 4. The structure type and the part number of each sample are listed in Table 2 along with the number of reference defects contained in each sample. Detailed information on the geometrical dimensions, material types, and construction of the samples is given in Appendix C (obtained from T.O. 1F-16A-36).

2. F-5 Honeycomb Structure Samples

The F-5 honeycomb structure standard kit consisted of a total of 16 samples representing a variety of parts used on the F-5F and the F-5E aircraft. Figure 5 shows a photograph of the kit (Figure 5a) and a close-up view of some of the samples (Figure 5b). The description of the samples including the part number, structural applications, and the number of defects contained in each sample, is contained in Table 3. More specifics of the samples are given in Appendix D.

3. Graphite/Epoxy Samples

A total of three graphite/epoxy samples shown in Figure 6 were used in this laboratory evaluation. The samples were part of the Graphite/Epoxy NDI standards with built-in flaws fabricated at the Lockheed-Georgia Company (Ref: W. H. Sproat, "Composite NDI Proficiency Kit and Methodology, Hardware Design and Fabrication", Preliminary Report, Lockheed-Georgia Company, Contract No. F41608-83-D-A100, August 1986). The three samples were one impact damage standard, one delamination standard, and one repair patch standard. The identification number and the number of defects contained in each sample are described in Table 4. Further details of the samples are given in Appendix E.

C. Procedure

The instruments used in the laboratory evaluation were loaned to SwRI by the respective distributors and manufacturers.

The BondaScope 2100 came with eight different probes, each with a specific range of applicability. The diameter of the piezoelectric element in these probes ranged from 1/8 to 3/4 inch, and the operating frequency range was from 24 to 385 KHz.

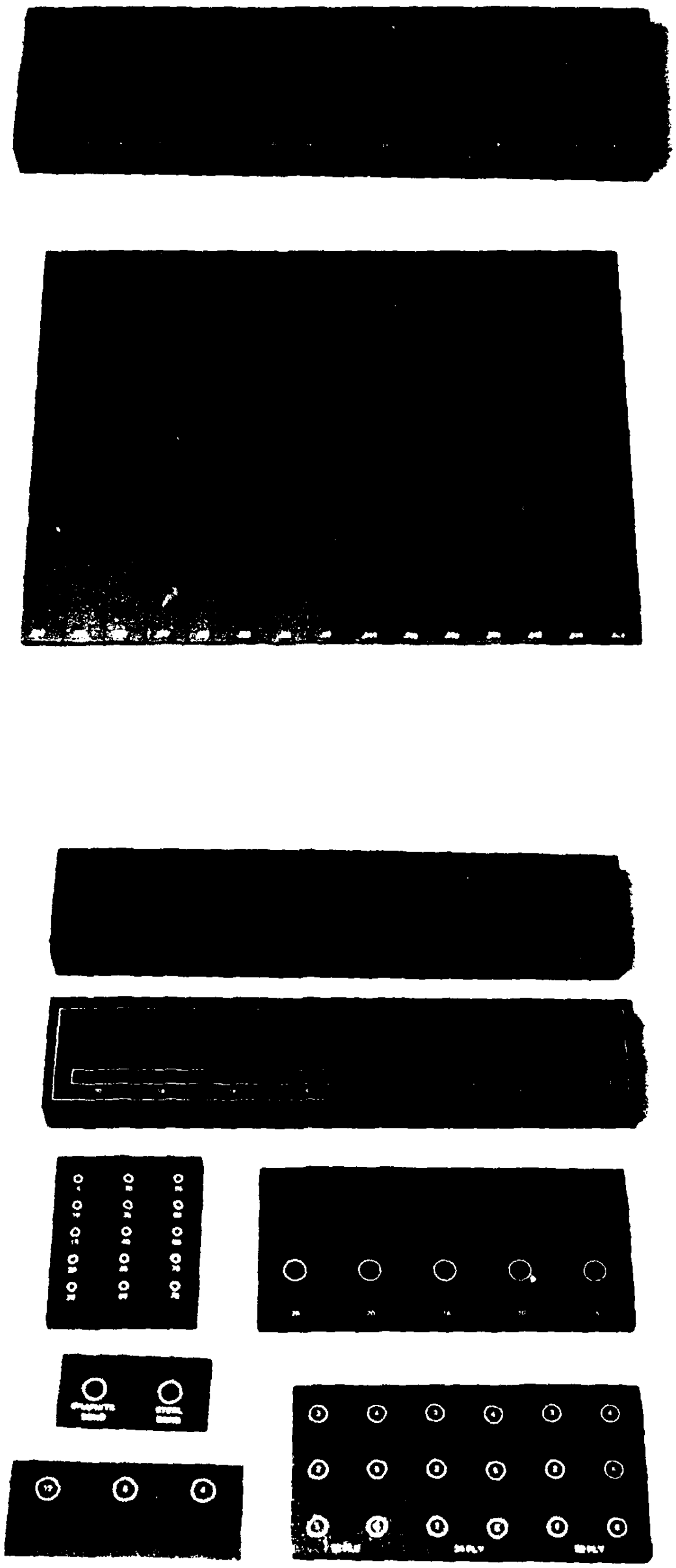


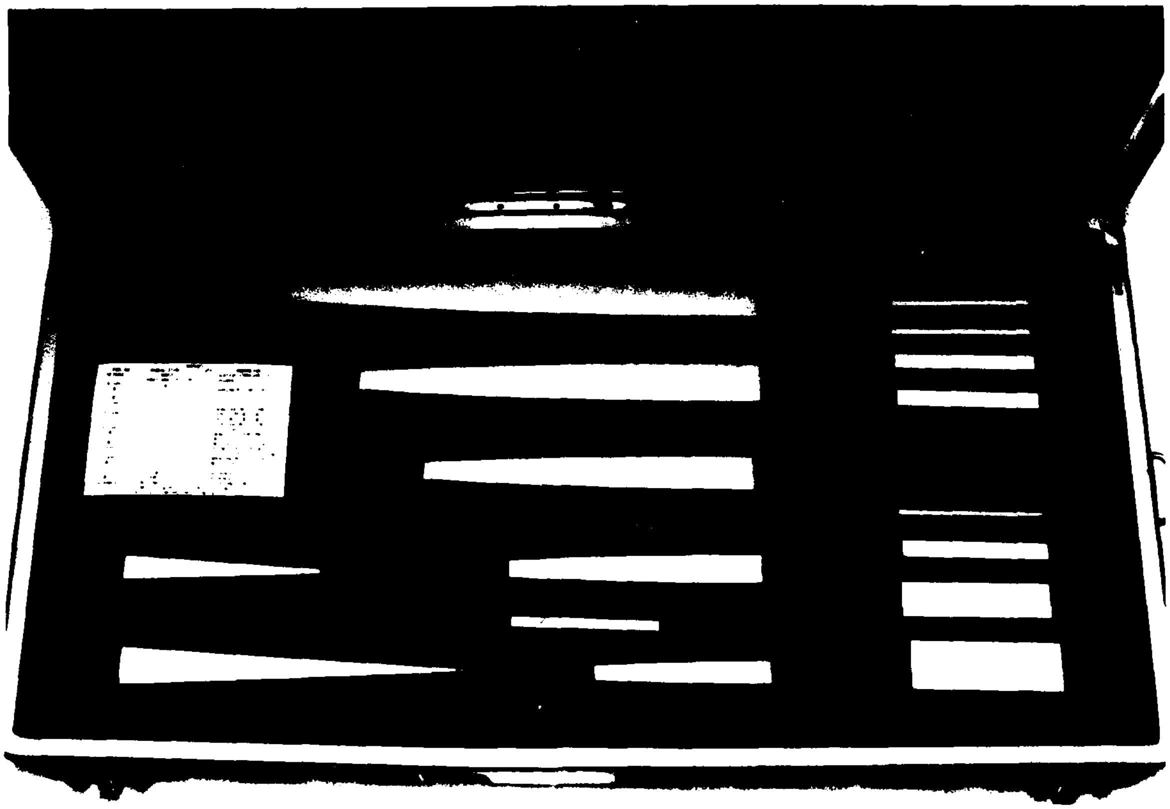
Figure 4. Photographs of F-16 Bonded Structure Samples

Table 2

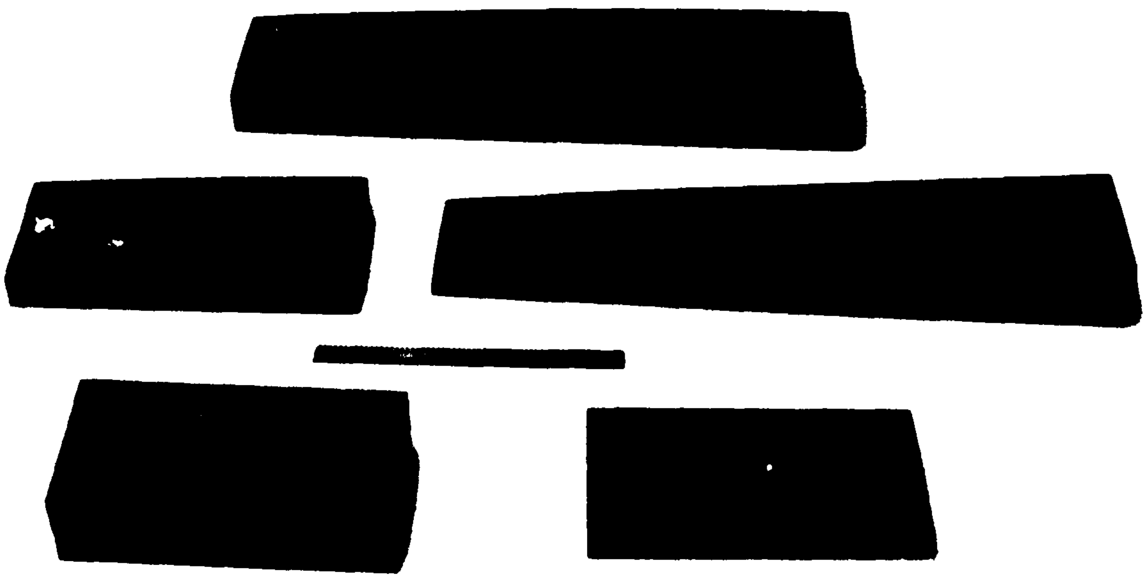
DESCRIPTION OF F-16 BONDED STRUCTURE SAMPLES

No.	Structure Type	Part No.	No. of Defects
1	Metal-to-Metal	16A11039-7	75
2	Metal-Aluminum Honeycomb Core	16A11039-9	16
3	Aluminum-Graphite/Epoxy	16A11033-7	5
4	Steel-Graphite/Epoxy-Fiberglass	16A11033-11	2
5	Graphite/Epoxy-Graphite/Epoxy	16A11033-13	3
6	Graphite/Epoxy-Aluminum Honeycomb Core	16A11033-15	8
7	Graphite/Epoxy-Aluminum Honeycomb Core	16A11033-109	8
8	Graphite/Epoxy Laminate	16A11033-9	15
9	Graphite/Epoxy-Fiberglass-Titanium	16A11033-17	18
		Total	150

Note: Except for samples 2, 6, and 7, the defects in these samples are flat-bottom holes. The diameter of the flat-bottom holes is, respectively, 0.75 inch for sample 1, 0.62 inch for samples 3-5, 0.25 inch for sample 8, and 0.5 inch for sample 9. The defects in samples 2, 6, and 7 are made by cutting out the honeycomb core. The width of the cutout is 0.75 inch for sample 2 and 0.5 inch for samples 6 and 7.



(a) Photograph of the Whole Kit



(b) Photograph of Some of the Samples

Figure 5. Photographs of F-5 Honeycomb Structure Samples

Table 3

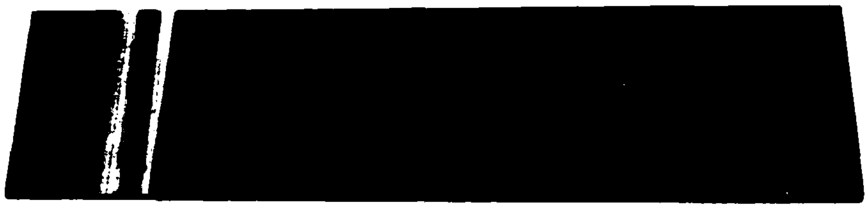
DESCRIPTION OF F-5 HONEYCOMB STRUCTURE SAMPLES

No.	Part No.	Applications	No. of Defects
1	14-76444-1	Vertical Stabilizer T/E Rudder	4
2	14-76445-5	Horizontal Stabilizer L/E	4
3	14-76445-7	Horizontal Stabilizer L/E	4
4	14-76445-9	Horizontal Stabilizer L/E	3
5	14-76445-11	Horizontal Stabilizer L/E	3
6	14-76445-13	Horizontal Stabilizer L/E	3
7	14-76446-1	Trailing Sections of Wing, Horizontal Stabilizer, Aileron, and Flap	4
8	14-76447-1	Vertical Stabilizer L/E	2
9	14-76447-3	Wing Upper Skin Panel	2
10	14-76447-5	Nose Gear Door	2
11	14-76447-7	M.L.G. Articulated Door, Avionics Bay Door*, Access Door F.S. 47.5-87.5*	2
12	14-76448-1	Main Landing Gear Door	2
13	14-76448-3	M.L.G. Door Outboard	2
14	14-76448-5	M.L.G. Door Outboard	2
15	14-76448-7	Access Door and Bay Skin of Aileron	2
16	14-76448-9	Floor Panels*	2
		Total	53

Note: Applications marked with * are for use on the F-5F only. All other items are for use on both the F-5E and the F-5F. All the defects are flat-bottom holes with diameters of 0.5 inch for samples 2-6 and 0.25 inch for the others.

Delamination Sample

Repair Patch Sample



Impact Damage Sample

Figure 6. Photograph of Graphite/Epoxy Samples

Table 4

DESCRIPTION OF GRAPHITE/EPOXY SAMPLES

No.	I.D. No.	Description	No. of Defects
1	ID-6	Impact Damage Standard	2
2	DL-8	Delamination Standard	2
3	RP-7	Repair Patch Standard	6
		Total	10

Note:

#1. The Impact Damage standard was a 32-ply graphite/epoxy laminate with flaws produced by hitting the standard with a weight dropped from a given height. One of the defects was 3/8 inch in diameter and was produced by an 80 in-lb impact. The other defect was a cluster of three 1/4-inch diameter damaged areas, each produced by a 40 in-lb impact.

#2. The Delamination standard was a 12-ply graphite/epoxy laminate bonded as face sheets to one-inch-thick aluminum honeycomb core. Delamination flaws were simulated by inserting Teflon envelopes between laminate layers. There were two flaws; one placed in the front face sheet (1/2 inch diameter) and the other placed in the back face sheet (1/4 inch diameter).

#3. The Repair patch standard consisted of a 36-ply graphite/epoxy laminate base with a 36-ply graphite/epoxy laminate on top with 1/2-inch ply dropoffs. The sample contained one 1% bondline porosity defect 3/4 inch in diameter, one 3% bondline porosity defect area, two rectangular delamination defects 1/4 x 1/2 inch and 1/8 x 1/2 inch, respectively, and two square delamination defects 1/2 x 1/2 inch.

The AET model 206 AU instrument came with one wheeled probe with a fixture and two AC 375 LM acoustic sensors. The piezoelectric crystals used in the wheeled probe and the acoustic sensors had a resonance frequency of 375 KHz. The fixture for the wheeled probe maintained a fixed distance between the transmitting and receiving transducers.

The UFD-S instrument came with one roller probe (Model RP 25-1) and one rubber tip probe (Model STP 5-12) and accompanying fixtures. Each probe consisted of one transmitting and one receiving transducer. The fixture allowed adjustment of the distance between the transducers and the angle of each transducer with reference to the surface of the part under inspection.

The Fokker Bondtester Model 80 L came with nine different probes and four different probe adaptors. Each combination of probe and adaptor had a specific range of applicability (details are described in the operating manual). The diameter of the piezoelectric crystal in these probes ranged from 0.25 to 1.5 inches.

The flaw detectability of each of the instruments was evaluated using the reference bonded structure samples described in the previous section. The instruments were adjusted or calibrated according to their respective operating manuals. The appropriate probes were also selected according to the respective manuals. The AET Model 206 AU and the UFD-S instruments were adjusted by using a comparative procedure whereby the probe was placed over known good areas and known flaws, respectively, and the instrument controls adjusted so that the flawed region produced a measurably different response compared to a good bonded region. The BondaScope 2100 and Fokker Bondtester Model 80 L were calibrated according to the procedures described in their respective manuals, which involved a nulling procedure whereby the probe was placed over known good areas or known flaws and the instrument controls adjusted so that the instrument response was at specified null conditions. Since the instrument adjustment and/or calibration depended on the particular construction of the specimen (type of material, total thickness of the specimen, and thickness of face sheet) and selection of the probe, readjustment of the instruments was generally required whenever the construction of a specimen varied or a different probe was used.

With all four instruments, the reference bonded specimens described in the previous section were examined and the detectability of the known reference defects was determined. Unless otherwise specified, examinations were made from the front sides of the specimens.

D. Results

The results of the flaw detectability evaluation for the four selected instruments are presented in Table 5. To avoid identifying the performance of each individual instrument in this report, the instruments are renamed alphabetically in no specific order in the table. The identifications of the instruments were separately provided to SA-ALC/MMEI.

For the sake of the simplicity in presenting the results, the overall performance of the instrument in detecting the flaws contained in each specimen

is given in Table 5, instead of the detectability of each individual flaw. When the detectability of some of the flaws in a specimen differed from that shown in Table 5, the difference is described at the bottom of the table. There were a total of 28 specimens containing a total of 212 reference flaws for examination. In some cases (instruments B and C), not all the reference flaws were examined because of the lack of appropriate probes for certain geometric construction types. For instance, some thick-skin portions of the specimens were beyond the specified applications of the available probes, and some portions of the specimens were too narrow to accommodate the probes. Any such limitations are also noted at the bottom of the table.

In Table 5, the flaw detectability is expressed by using the following four ratings: very good (VG), good (G), fair (F), and poor (P). The ratings were defined by using the following criteria based on the flaw signal to noise (S/N) ratio:

Rating	S/N Ratio
Very Good (VG)	egual to or greater than 5
Good (G)	equal to or greater than 3 and less than 5
Fair (F)	equal to or greater than 2 and less than 3
Poor (P)	less than 2

Here, flaw signal refers to the magnitude of the instrument response to a flaw and noise refers to the magnitude of the variations in the instrument response from good bonded areas.

On the F-16 bonded structure samples, instruments A and D showed a good to very good flaw detectability. Also, instrument B generally showed a good to very good flaw detectability except the metal-aluminum honeycomb core sample on which the instrument showed a poor flaw detectability. Instrument C exhibited a good detectability on only a few specimens indicating a limited applicability. In addition, instrument A showed a potential for measuring the depth location of a debond in a laminate structure within the accuracy of a few plies and a debond in a multi-bonded structure. Instruments B and D showed a limited capability of identifying the debonded interface in a multi-bonded structure.

On the F-5 honeycomb samples, instrument A exhibited poor to fair flaw detectability. In general, the flaw indications on instrument A were not prominent and a very close attention of the inspector was required to identify the flaws. The inspection was therefore time consuming. Both instruments B and C, on the other hand, showed poor flaw detectability. Instrument D showeda very good detectability of the 1/2 in. diameter debonds in samples Nos. 2-6, while the detectability of the 1/4 in. diameter debonds in the rest of the samples was poor. It took a considerable time to calibrate instrument D; however, once calibrated, the inspection was straightforward and fast. In addition, flaw indications on instrument D were not influenced by the tapering (gradual thickness decrease) in the samples and, therefore, no readjustment of the instrument settings was needed to inspect the tapered section of the samples.

Table 5

LABORATORY EVALUATION RESULTS ON THE FLAW DETECTABILITY OF FOUR SELECTED INSTRUMENTS

Reference Samples	Flaw Detectability A	B	C	D
F-16 Bonded Structure Samples (Ref.Table 1)				
1. Metal-Metal	G-VG(1)	G(2)	-(3)	G(4)
2. Metal-Al Honeycomb Core	G-VG(5)	P	P	VG
3. Al-Graphite/Epoxy	VG	G-VG	G	VG
4. Steel-Graphite/Epoxy-Fiberglass	G-VG	G	G	G-VG
5. Graphite/Epoxy-Graphite/Epoxy	VG	VG	F(6)	VG
6. Graphite/Epoxy-Al Honeycomb	G-VG	G-VG	P(7)	VG
7. Graphite/Epoxy-Al Honeycomb	G-VG	F(8)	P	VG
8. Graphite/Epoxy Laminate	G-VG	F-G(9)	P	G-VG(10)
9. Graphite/Epoxy-Fiberglass-Titanium	G-VG	F-G(11)	P	G-VG(12)

Notes:

(1) Fair for the cases where lower sheet thickness is 0.05 in. and upper sheet thickness is 0.19 in. or greater, and lower sheet thickness is 0.10 in. and upper sheet thickness is 0.21 in. or greater.

(2) For up to 0.19 in. upper sheet thickness. Those with upper sheet thickness greater than 0.19 in. were not inspectable because of the lack of an appropriate probe.

(3) Not examined because of the lack of an appropriate probe.

(4) Poor for the cases where lower sheet thickness is 0.05 in. and upper sheet thickness is 0.15 in. or less.

(5) Poor for those with skin thickness of 0.17 in. or greater.

(6) Poor for 12 ply skin.

(7) Good for 6 ply skin.

(8) Poor for 40 to 44 ply skins.

(9) Poor for the holes at 70 and 75 ply depths.

(10) Fair for the holes at 30 to 50 ply depths. Poor for holes at a depth greater than 50 plies.

(11) Good to Very Good for 18 ply skin.

(12) Poor for Nos. 1 - 4 holes under the 52 ply graphite/epoxy laminate.

Table 5 (Cont'd)

LABORATORY EVALUATION RESULTS ON THE FLAW DETECTABILITY
OF FOUR SELECTED INSTRUMENTS

Reference Samples	Flaw Detectability A	B	C	D
F-5 Honeycomb Structure Samples (Ref. Table 2)				
1. Vert. Stab. T/E Rudder	P	P	P	P
2. Horiz. Stab. L/E	F	P	P	VG
3. Horiz. Stab. L/E	F	P	P	VG
4. Horiz. Stab. L/E	P	P	P	VG
5. Horiz. Stab. L/E	F-G	P	P	VG
6. Horiz. Stab. L/E	P	P	P	VG
7. Trailing Sections of Wing et al.	F-G	P	P	P
8. Vert. Stab. L/E	P	P	P	P
9. Wing Upper Skin Panel	P	P	P	P
10. Nose Gear Door	F	P	P	P
11. M.L.G. Articulated Door et al.	F	P	P	P
12. Main Landing Gear Door	P	P	P	P
13. M.L.G. Door Outbd	P	P	P	P
14. M.L.G. Door Outbd	F	P	P	P
15. Access Door and Bay Skin of Aileron	F	P	P	P
16. Floor Panels	F	P	P	P

Table 5 (Cont'd)

LABORATORY EVALUATION RESULTS ON THE FLAW DETECTABILITY OF FOUR SELECTED INSTRUMENTS

Reference Samples	Flaw Detectability A	B	C	D
Graphite/Epoxy Samples (Ref. Table 3)				
1. Impact Damage	VG	F-G	P	VG
2. Delamination[(1)]	VG	P	F-G	VG[(2)]
3. Repair Patch	G[(3)]	P	P	P

Notes:

(1) The results were based on the near surface inspection. From the face sheet opposite to the sheet where the flaw was located, the flaw was not detectable.

(2) Poor for 1/4 inch diameter delamination.

(3) Poor for the bondline porosity and one of the 1/2 x 1/2 inches patch delamination.

On the graphite/epoxy samples, instrument A showed a good to very good detectability of impact damage and delaminations. Instrument D exhibited a very good flaw detectability on the impact damage and delamination samples but showed a poor detectability on the repair patch sample. Instruments B and C showed only a limited detectability. All the four instruments used showed a poor detectability of the bondline porosity (up to 3%) in the repair patch sample.

Generally speaking, inspection with instruments requiring a liquid couplant was slow and time consuming, and the inspection results were sensitive to the coupling state of the probe to the specimen. The responses of the instruments operated with dry-coupled probes were also sensitive to the amount of force applied to the probe. This observation indicated that coupling variations of the dry-coupled probes also influenced the inspection results. Therefore, for both fluid-coupled and dry-coupled probes, care must be exercised to maintain a consistent and uniform coupling in order to obtain reproducible instrument responses.

Overall, instruments A and D performed very well. Instrument B showed a good performance while instrument C showed only a limited applicability. Of the four instrumnets evaluated, instrument A was the easiest to calibrate and operate. The inspection speed with instrument A, however, was slow. Instrument D, on the other hand, was easy to operate and the inspection was fast. However, calibration and adjustment of instrument D for optimum flaw detection require skill and experience and may take considerable time. Instrument B was easy to calibrate but the inspection was slow. The probes were somewhat inconvenient to use. Instrument C, in its present form, was somewhat difficult to use and may not produce consistent results.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. More than fifty commercial ultrasonic instruments are available for nondestructive inspection of bonded aircraft structures. The majority of these instruments are conventional ultrasonic flaw detectors based on pulse-echo and through-transmission techniques. The rest of the instruments, which comprise a small minority, are based on nonconventional techniques including the resonance technique, the shadow technique, and the acousto-ultrasonic technique.

2. The trend in ultrasonic instruments is toward digital, automatic, and computer-controlled instruments. The majority of the commercial instruments are microprocessor-controlled with interfaces for communication with other devices such as an external computer, a printer, a recorder, or a video display. Also, the majority of the instruments are modular in construction to facilitate maintenace and repair. In addition, almost all instruments are equipped with visual and/or audible alarms to aid in flaw detection.

3. Most of the instruments use sensors (or probes) which require a liquid couplant such as light machine oil or water to transmit ultrasonic energy through the contacting interfaces between the probe and the part under inspection. Several instruments are operated with dry-coupled probes which do not require a liquid couplant. The dry-coupled probes use a pliable and resilient material such as rubber to transfer ultrasonic energy from the piezoelectric crystal to the part under inspection and vice versa. The degree of coupling of both the liquid-coupled and dry-coupled probes influence the inspection results. Therefore, to obtain repeatable results, uniform and consistent coupling of the probes is required.

4. Almost all the instruments require a smooth and clean surface of the part for inspection. However, substantial surface preparation such as removing paint on the part is not generally required. In addition, most of the instruments are operable in field environmental conditions. Except for highly sophisticated and automatic instruments and some instruments operated with a wheel type probe, the inspection speed of the instruments are generally slow. The portability of the instruments is generally high. Also, about 50% of the instruments are battery operable. The operating time of the batteries varies with each instrument but ranges typically from 6 to 12 hours. The equipment cost varies over a wide range from several thousand dollars to over a quarter of million dollars depending on the degree of sophistication and automation.

5. A total of four instruments was evaluated in the laboratory. Two instruments were based on the resonance technique, one was based on the shadow technique, and the other was based on the acousto-ultrasonic technique. A total of 28 reference bonded structure samples which contained a total of 213 reference flaws were used. The reference samples represented a wide variety of bonded aircraft structures including metal-to-metal, composite-to-metal, composite laminates, metal-honeycomb-metal, and composite-honeycomb-composite structures.

6. Instrument A showed generally a good to very good detectability of the flaws in the reference samples used except the F-5 honeycomb structure samples. The instrument also demonstrated the potential for determining the depth location of a debond in a laminate structure (within the accuracy of a few plies) and in a multi-bonded structure. The instrument setup and operation were straightforward. Recalibration of the instrument was required when the geometry or thickness of a part under inspection varied. The inspection time was slow.

7. Instrument B showed generally a good flaw detectability except for the flaws in the metal-aluminum honeycomb-metal structure samples. The instrument was easy to calibrate. Inspection speed was slow. Recalibration was required when the geometry or thickness of a part under inspection varied.

8. Instrument C showed a good flaw detectability on only a small number of samples thus indicating its limited applicability to inspection of bonded structures.

9. Instrument D generally showed a good to very good flaw detectability. The instrument performed particularly well in detecting debonds (of the diameter 0.5 inch or larger) between the skin and the core of metal-aluminum honeycomb-metal structures. The taper in the F-5 samples did not influence the flaw detection. The instrument was easy to operate and the inspection was fast. Setting up and calibration of the instrument for optimum flaw detection required skill and experience and might take a considerable amount of time.

10. The four instruments evaluated showed a poor detectability of the bondline porosity up to the 3% porosity investigated.

B. Recommendations

1. Instruments A and D are recommended for nondestructive inspection of bonded aircraft structures.

2. Development of inspection procedures including instrument setup and calibration for each specific inspection application is recommended.

3. A study of the effects of the real world problems encountered such as dents, hail damage, and variation in paint thickness on the inspection results and their reliability is recommended.

APPENDIX A

NAMES AND MANUFACTURERS OF ULTRASONIC INSTRUMENTS FOR INSPECTION OF BONDED STRUCTURES

No.	Equipment Name	Manufacturer
1.	Ultra Image III	Ultra Image International
2.	Acousto-Ultrasonics Instrumentation System	Physical Acoustics Corp.
3.	Multisonic/PC	California Data Corp.
4.	UFD-S Ultrasonic Flaw Detector	Sonatest
5.	Zipscan 2	SGS Sonomatic Ltd.
6.	Sparta TTU-90	Sparta Technology
7.	USIP 12 Ultrasonic Flaw Detector	Krautkramer Branson
8.	USIP 11 Ultrasonic Flaw Detector	Krautkramer Branson
9.	PARIS (Portable Automated Remote Inspection System)	Sigma Research, Inc.
10.	SDL-1000 Ultrasonic Imaging System	Sigma Research, Inc.
11.	Sigma Series 2000 Ultrasonic Imaging System	Sigma Research, Inc.
12.	USD-1	Krautkramer Branson
13.	Fokker Bondtester Model 80 L	Fokker B.V.
14.	M-Series Ultrasonic Instrument	Nortec/Metrotek
15.	NDT-132 Portable Ultrasonic NDT Instrument	Nortec/Metrotek
16.	AET Model 206AU Acousto-Ultrasonic Instrument	Acoustic Emission Technology Corp.
17.	NovaScope 3000	Automation/Sperry
18.	NovaScope 2000	Automation/Sperry
19.	BondaScope 2100	NDT Instruments, Inc.
20.	Bondtester 210	NDT Instruments, Inc.
21.	S-1A Sondicator Ultrasonic Test Instrument	Automation/Sperry

No.	Equipment Name	Manufacturer
22.	S-2B Sondicator Ultrasonic Test Instrument	Automation/Sperry
23.	PS-710B Pulse Ultrasonic Test Unit	Magnaflux Corp.
24.	FX-3 Ultrasonic Flaw Detector	Magnaflux Corp.
25.	FX-5 Ultrasonic Flaw Detector	Magnaflux Corp.
26.	FX-7 Ultrasonic Flaw Detector	Magnaflux Corp.
27.	Echograph 1150 Ultrasonic Instrument System	Karl Deutsch
28.	Echograph 1030 Portable Modular Ultrasonic Flaw Detector	Karl Deutsch
29.	Echograph 1030-QUASCO Portable Ultrasonic Quality Assurance System	Karl Deutsch
30.	Echograph Series 10 Portable Ultrasonic Flaw Detector	Karl Deutsch
31.	Echograph Series 20 Portable Ultrasonic Flaw Detector	Karl Deutsch
32.	Nanoscope 412 Ultrasonic Flaw Detector	Erdman Instruments Inc.
33.	Epoch 2002 Flaw Detector	Panametrics
34.	5052UA Ultrasonic Analyzer	Panametrics
35.	5055UA Ultrasonic Analyzer	Panametrics
36.	TenEleven SG Flaw Detector	Baugh & Weedon Ltd.
37.	PA1020 Ultrasonic Flaw Detector	Baugh & Weedon Ltd.
38.	MIA 3000 Structural Integrity Monitor	Inspection Instruments Ltd.
39.	USL 33 Ultrasonic Flaw Detector	Krautkramer Branson
40.	USL 48 Ultrasonic Flaw Detector Digital Thickness Instrument	Krautkramer Branson
41.	USM 3 Large Screen Ultrasonic Flaw Detector	Krautkramer Branson
42.	USM 3S Large Screen Ultrasonic Flaw Detector	Krautkramer Branson

No.	Equipment Name	Manufacturer
43.	Intraspect 98 Ultrasonic Imaging System	Combustion Engineering
44.	KB-6000 Ultrasonic Instrumentation System	Krautkramer Branson
45.	QC-2000 Reflectoscope	Automation/Sperry
46.	QC-400 Reflectoscope	Automation/Sperry
47.	M-90 Reflectoscope	Automation/Sperry
48.	S-80 Reflectoscope	Automation/Sperry
49.	CM 2000 Squirter Ultrasonic Scanning System	Custom Machine Inc.
50.	MBS-8000 Computer Controlled Ultrasonic Testing System	MATEC Instruments Inc.
51.	NDT-150 Ultrasonic Inspection System	Nortec/Metrotek
52.	NDT-131D Digital Ultrascope	Nortec/Metrotek
53.	1712A Computerized Ultrasonic Instrument	Systems Research Lab., Inc.
54.	AX-8000 Integrity Tester	American NDT, Inc.
55.	FD-700 Ultrasonic Flaw Detector	Mitsubishi Electric Corp.
56.	Mark IV Ultrasonic Flaw Detector	Sonic Instruments Inc.
57.	ARIS (Automated Realtime Inspection System)	Southwest Research Institute
58.	ABE (Advanced Bond Evaluator)	United Western Tech., Corp.

APPENDIX B

ULTRASONIC EQUIPMENT EVALUATION FORM AND RATING GUIDELINES

ULTRASONIC EQUIPMENT EVALUATION FORM

Equipment Name :

Manufacturer :

Based on Thru-Transmission/Pulse-Echo Tech. ( ), Resonance Tech. ( )

- -

Maximum Output Voltage of the Pulser : Spike, Square Wave Pulse

Receiver Gain ______dB, Dynamic Range ______dB, Freq. Range_________MHz

Flaw Sensitivity :
Flaw Type : Delaminations, Voids, Unbonds/Debonds, Subsurface Damage
Flaw Location : Near Surface, Sub-surface
Flaw Size :

Accuracy in Locating a Flaw : Position _________, Depth ___________

Dependency on Operator Skill :
Setup __________, Procedure ___________, Interpretation __________

Need of Surface Preparation _________, Need of Couplant __________

Sensitivity to Environmental Conditions:
Temp.______, Humidity ______, Light ______, Shock and Vibration ________

Inspection Speed :

Repeatability/Reliability of Inspection Results :

Availability of Recorder Interface :

Cost of Inspection (Including supplies and consumables) :

Portability of Equipment :_____________ Overall Weight __________

Maintainability of Equipment:
Modular Construction __________, Internal Diagnosis Capability ___________

Power Requirement :

Personnel Safety :

Equipment Cost :

Ability to Automate :
Adaptation/Modification Cost for Automation :

Remarks

RATING GUIDELINES

1. Flaw Sensitivity:

This rating pertains to the detectability of flaws of various types, sizes, and depths in a component. "Low" ratings refer to the case where the detectability is limited to flaws of a few specific types and a large size (1 inch or larger in diameter), and those located near the accessible surface. "High" ratings refer to the case where the detectability is good for various flaw types of small size (0.25 inch or smaller in diameter) throughout the thickness of the component. "Moderate" ratings are for the intermediate detectability.

2. Accuracy in Locating a Flaw:

This rating pertains to the accuracy and the resolution in determining the spatial position of a flaw in a component.

3. Dependency on Operator Skill

This relates to the training and skill required by the operator to conduct the inspection. "Low" ratings refer to minimal training (two days or less) and technical knowledge (high school graduation or equivalent experience) requirements. "High" ratings refer to the case in which a two-week or more training and a high level of technical knowledge (university graduation or equivalent experience) are required. "Moderate" ratings are for those cases which require training and technical knowledge intermediate between the "Low" and "High" ratings.

4. Need of Surface Preparation

This rating measures the amount of surface preparation required in the region to be inspected. "Low" ratings refer to the case where little or no preparation is required other than wiping the surface to remove loose foreign material such as dirt. "Moderate" ratings refer to the case where all foreign material adhered to the surface such as grease,oil or dirt must be removed and a clean surface is required. "High" ratings refers to the case where a substantial surface preparation such as removing paint is required.

5. Sensitivity to Environmental Conditions

This relates to the influence of field environmental conditions (temperature, humidity, light, shock, vibration, and noise) on the operation of the equipment and performing the inspection. "Low" ratings refer to the case where the equipment is adequate for use in the field condition. "Moderate" is for the case where the equipment is marginal for use in the field condition. "High" is assigned to the equipment whose use is limited to the laboratory condition.

6. Inspection Speed

This relates to the speed of inspection. "Low" ratings are assigned if the inspection is done manually. "Moderate" ratings are assigned if the inspection is done manually with the use of a mechanical device such as yoke which facilitates the inspection. "High" ratings are assigned if the inspection is done by using a mechanical or electrical scanning device.

7. Repeatability/Reliability of Inspection Results

This rating pertains to the repeatability (or reproducibility) and the reliability of the inspection results. This is intended to identify the degree of variation in inspection results from day to day operation and from operator to operator. "Low" ratings are assigned if the inspection relies heavily on the subjective judgement of the operator and requires a high degree of operator interaction with the inspection process and operator's attention to detail. "Moderate" ratings are assigned if the equipment is provided with features such as visual or audible alarm to allow objective judgement of the operator and the dependence of the inspection results on the operator is low. "High" ratings are assigned if the equipment requires little or no operator's judgement.

8. Availability of Recorder Interface

This rating relates to the availability of outputs for recording inspection results such as amplitude, thickness, distance, or logic (yes or no; on or off) outputs. "Low" ratings are assigned if no recording output is available. "Moderate" ratings are assigned if any of the following outputs ia available; amplitude, thickness, distance, or logic. "High" ratings are assigned if all of the above outputs and A-scan output are available.

9. Portability of Equipment

This relates to the easiness in transporting the equipment by hand. "High" ratings are assigned if the equipment is equal to or less than 30 lbs. "Low" ratings are assigned if the overall weight of the equipment is over 200 lbs or the equipment has a component weighing more than 50 lbs. "Moderate" ratings are assigned if the overall weight of the equipment is no more than 200 lbs and no component exceeds 50 lbs.

10 Maintainability of Equipment

This relates to the easiness in maintaining the equipment including repair and calibration. "High" ratings are assigned if the equipment consists of easily exchangeable plug-in modules or has internal diagnosis capability. "Moderate" ratings are assigned if the equipment can be diagnosed with standard testing device such as an oscilloscope and can be repaired and calibrated at user's facility in the Air Force. "Low" ratings are assigned if the equipment requires a special testing instrument or must be maintained at the manufacturer's facility.

11. Power Requirement

This rating measures the power required to operate the equipment and to conduct inspections. "Low" is assigned for power requirements which can be fullfilled with batteries. "Moderate" refers to a power requirement of a few hundred watts which could be obtained from a portable generator. "High" refers to a requirement of an electrical power line.

12. Personnel Safety

This rating measures the relative amount of precaution required in operating the equipment during the inspection to protect inspection personnel and other personnel nearby.

13. Equipment Cost

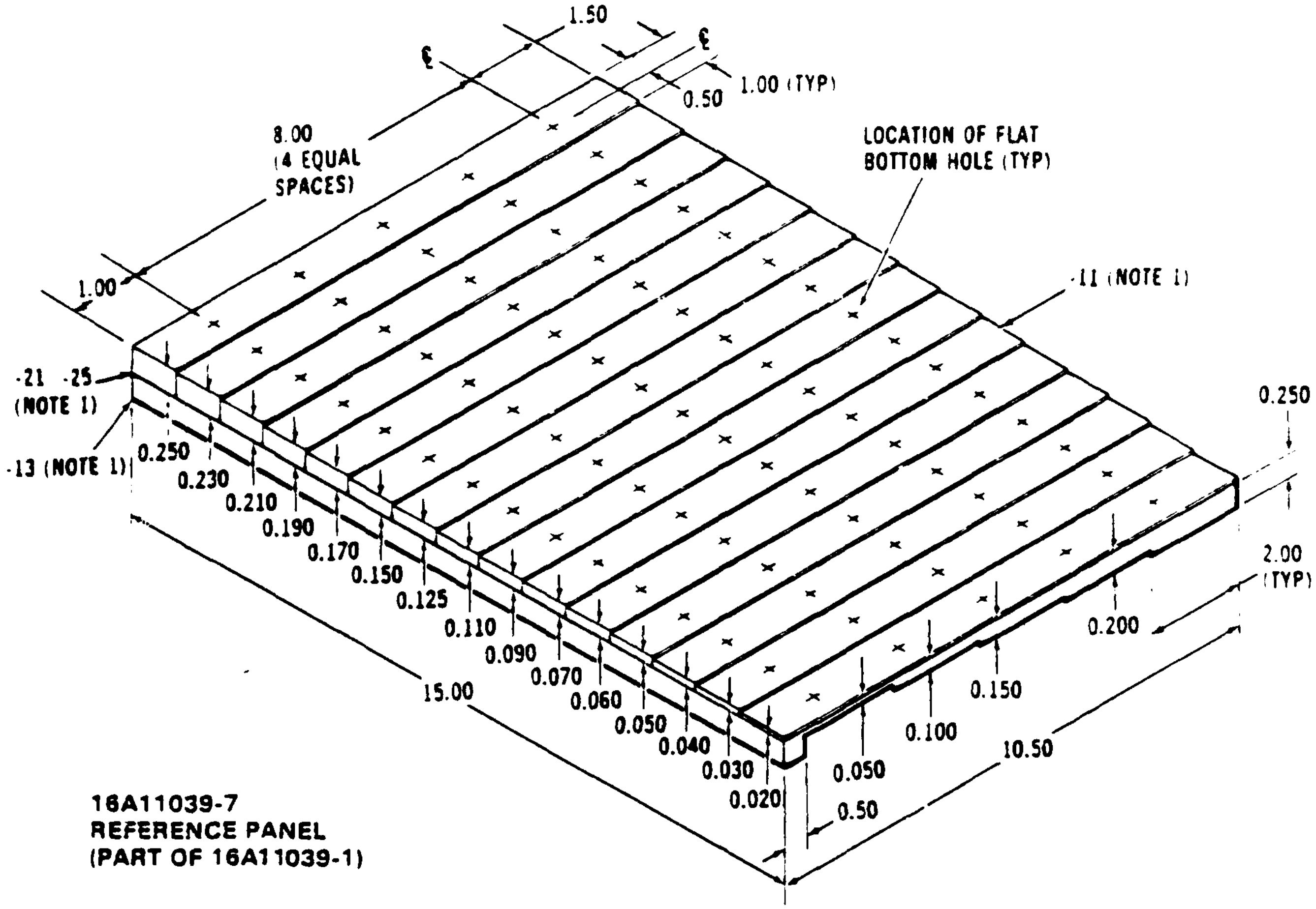
This rating pertains to the cost of the basic equipment excluding periperal equipment. "Low" is assigned if the equipment is equal to or less than $10,000. "Moderate" is assigned if the equipment is above $10,000 and equal to or less than $30,000. "High" is assigned if the equipment is above $30,000.

14. Ability to Automate

This rating refers to the capability of the equipment for automatic inspection. "Automated" is assigned if the equipment is already automated. "High" is assigned if the equipment is controllable using a microprocessor or a computer. "Moderate" is assigned if the equipment is manually controlled but can provide a digital output for data acquisition , process, and analysis using a computer. "Low" is assigned if the equipment is manually controlled and provides an analog output.

APPENDIX C

DESCRIPTION OF F-16 BONDED STRUCTURE REFERENCE SAMPLES (FROM T.O. 1F-16A-36)

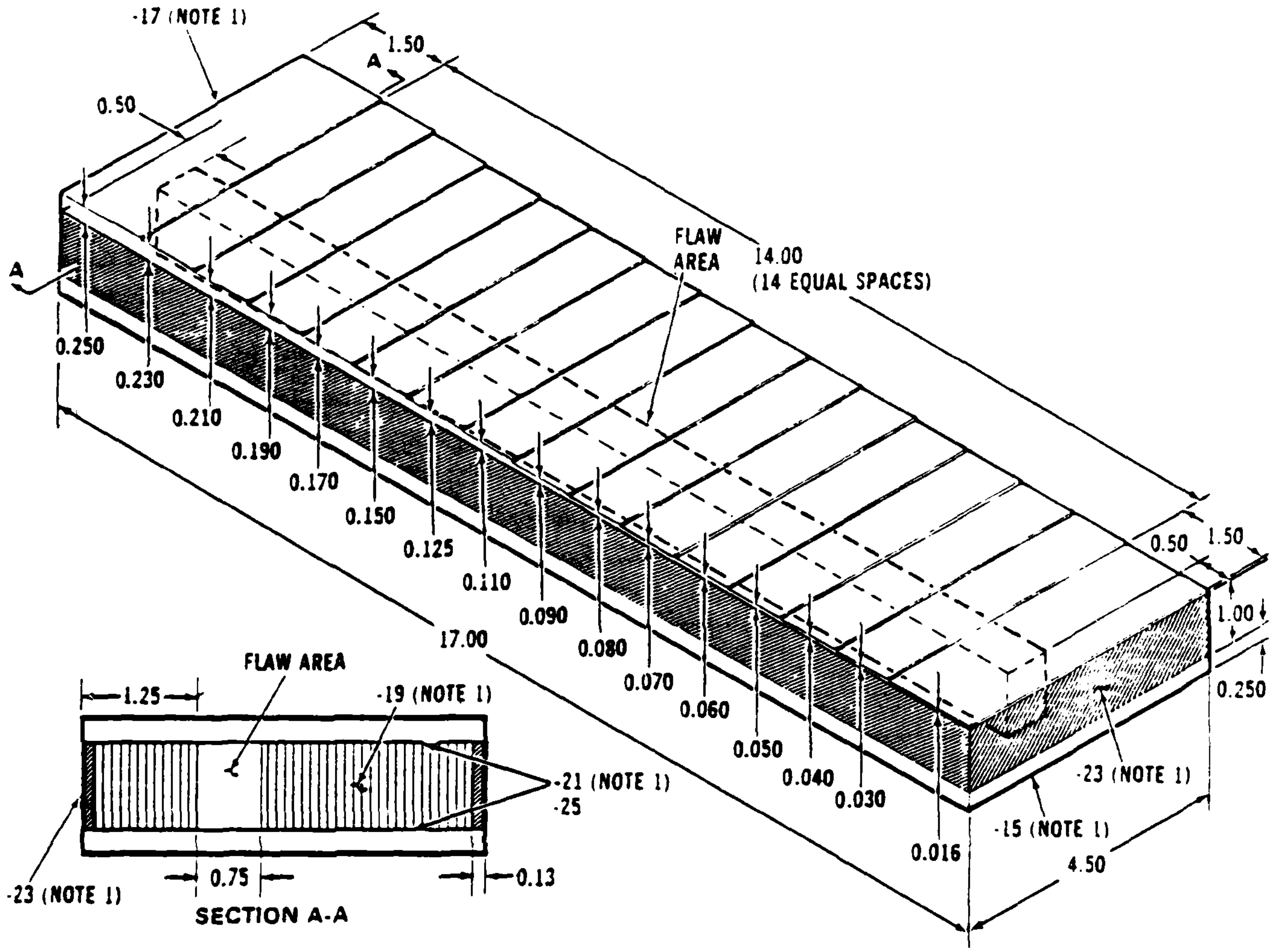


16A11039-7
REFERENCE PANEL
(PART OF 16A11039-1)

NOTES:

1. Materials: (See table 1-3.)
   -11/-13, 2024-T851 aluminum
   -21, FMS-3018, Form IB adhesive
   -25, FMS-3018, Form II adhesive primer
2. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
3. After evaluation of reference part for bond line integrity, drill 0.75-inch diameter flat bottom holes from bottom surface of reference part to adhesive bond line.
4. Finish: one coat epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286).

Figure 16A11039-7 Metal-Metal Reference Part



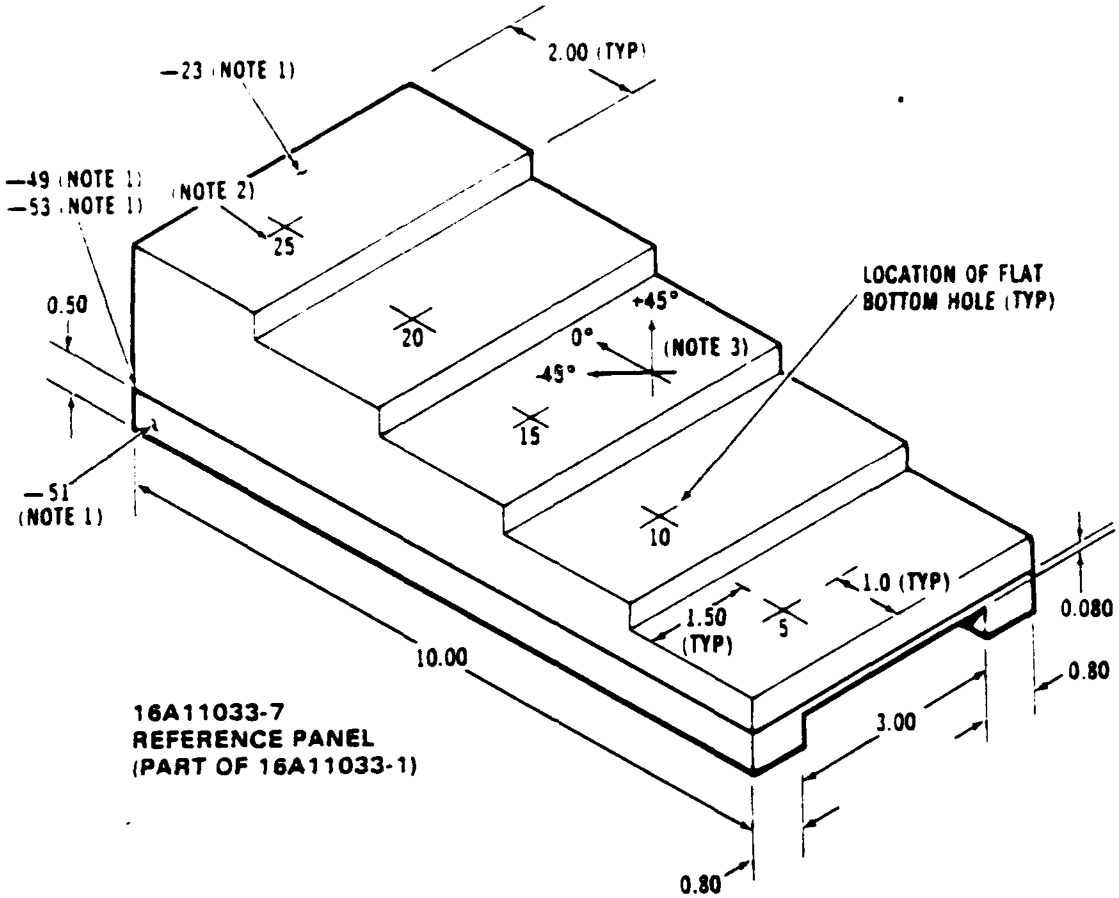
NOTES:

1. Materials: (See table 1-3.)
   - -15/-17, 2024-T851 aluminum
   - -19, P190-18 (5052-18) aluminum core
   - -21, FMS-3018, Form IB adhesive
   - -23, FMS-1044, Type V sealant
   - -25, FMS-3018, Form II adhesive primer
2. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
3. Install flaw area as follows:
   a. Cut plug from core.
   b. Install teflon tape on cut sides of plug and reinstall plug in core.
   c. Bond stepped top to core. Insure waffle imprint of plug remains in the adhesive.
   d. Remove plug and discard.
   e. Bond bottom skin.
   f. Seal exposed areas of core with sealant.
4. Finish: one coat epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286).

16A11039-9
REFERENCE PANEL
(PART OF 16A11039-1)

NOT 16 0590

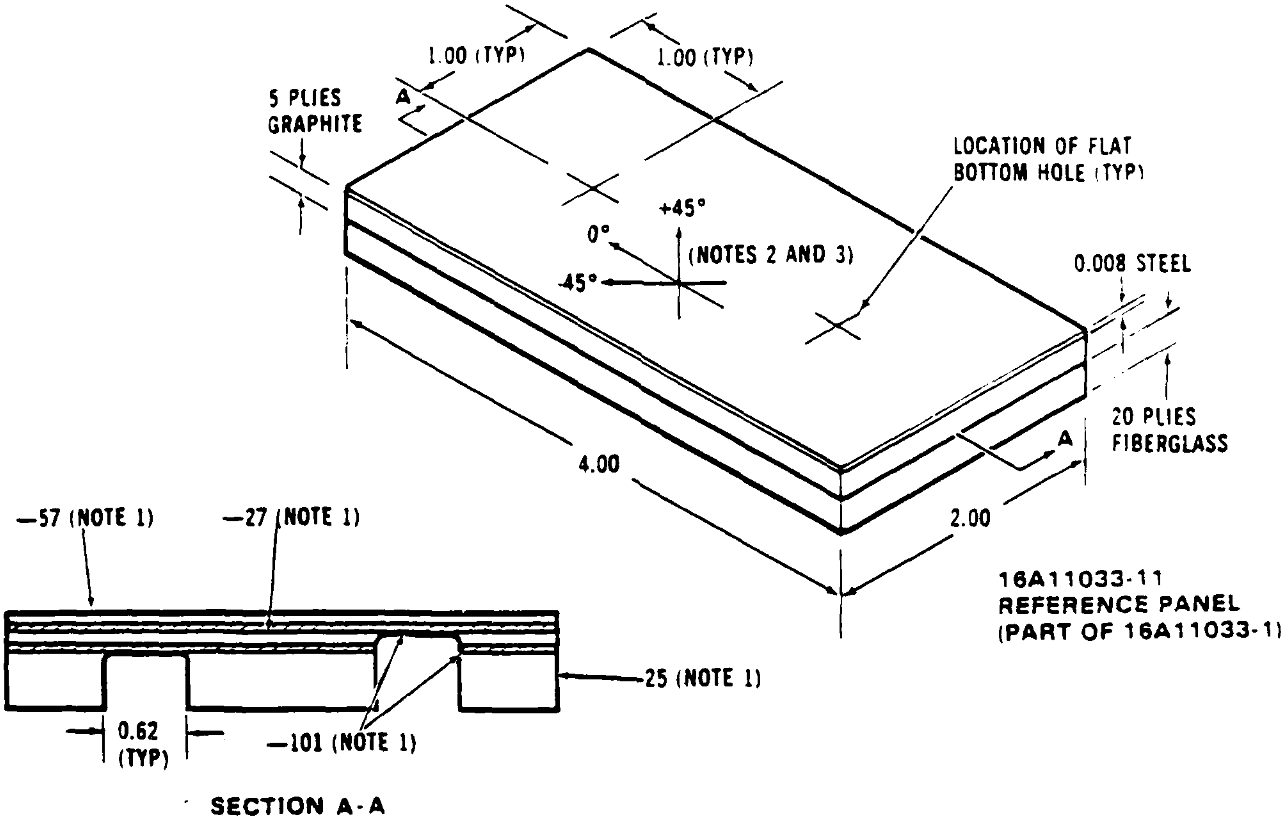
Figure 16A11039-9 Metal-Core Reference Part



NOTES:

1. Materials: (See table 1-3.)
   - —23. FMS-2023, Type 3 or Type 5, Form A or Form C graphite-epoxy tape.
     - P5284-3 cloth (1 ply-upper surface),
     - P5362-1 cloth (1 ply-lower surface)
   - —49. FMS-3018, Form II adhesive primer
   - —51. 2024-T851 aluminum
   - —53. FMS-3018, Form IB adhesive
2. Ply designation indicates thickness of step.
3. Every 5 plies of graphite-epoxy are oriented +45°, -45°, 0°, -45°, and +45°. This pattern is repeated 2, 3, 4, and 5 times, respectively, for 10, 15, 20, and 25 ply thicknesses.
4. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
5. After cure, drill 0.62-inch diameter flat bottom holes from aluminum side of reference part to adhesive bond line.
6. Finish:
   a. Composite—two coats epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286).
   b. Aluminum—one coat epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286), except holes which are unfinished.

Figure 16A11033-7 Aluminum-Graphite Reference Part

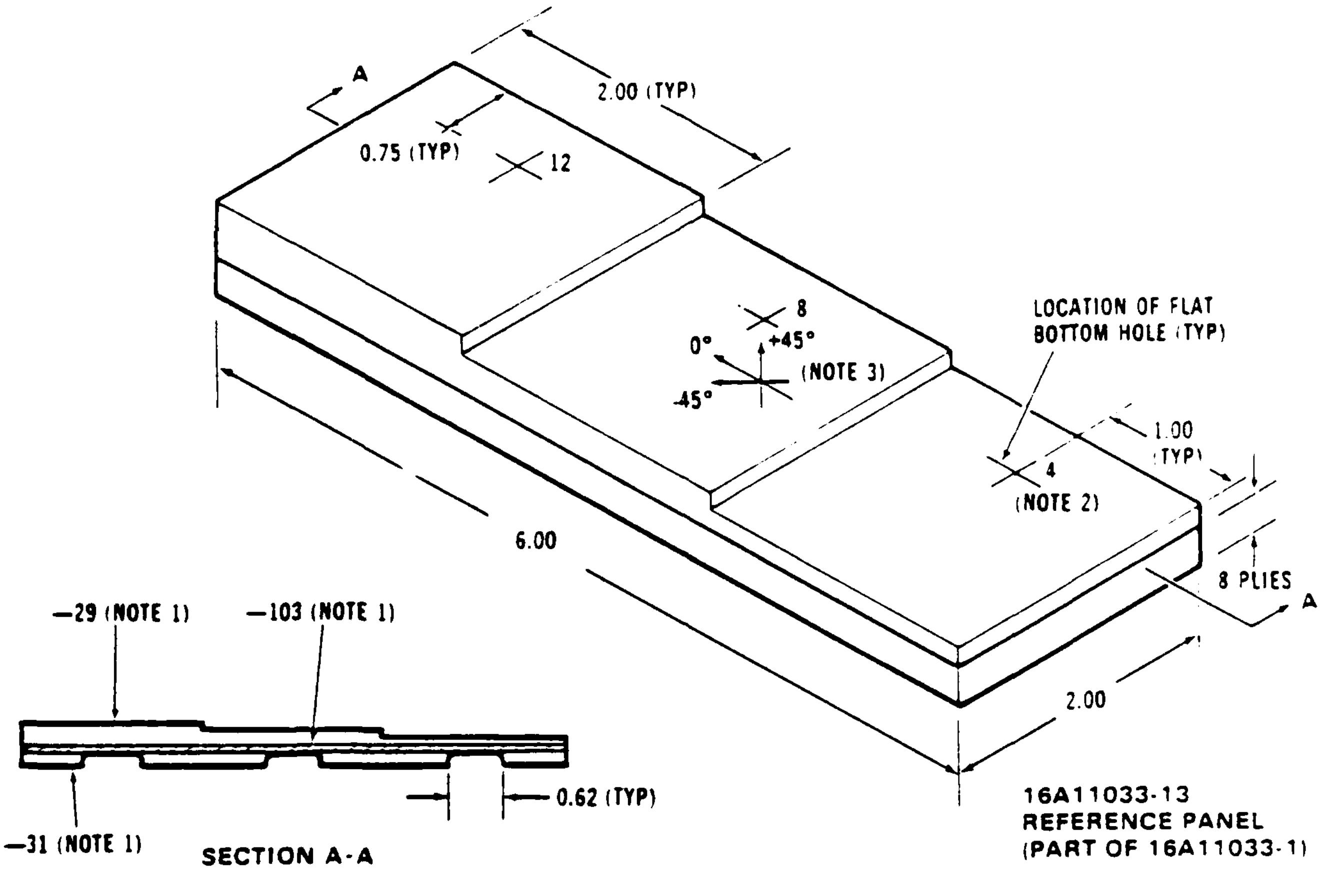


NOTES:

1. Materials: (See table 1-3.)
   - —25. FMS-1023. Class 1. Type A fiberglass
   - —27. FMS-2023. Type 3 or Type 5. Form A or Form C graphite-epoxy tape
   - —57. CRES Type 321 annealed steel (Military Specification MIL-S-6721)
   - —101. FMS-3018. Form IB adhesive
2. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
3. Orientation of graphite-epoxy plies is +45°. -45°. 0°. -45°. and +45°
4. Orientation of each ply of fiberglass is 90° to adjacent plies. e.g., +45°. -45°. +45°. -45°. etc.
5. After cure. drill flat bottom holes as shown.
6. Finish:
   a. Composite and laminate—two coats epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286), except holes which are unfinished.
   b. Metallic—one coat epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286).

NOT 16 0828

Figure 16A11033-11 Steel-Graphite Reference Part

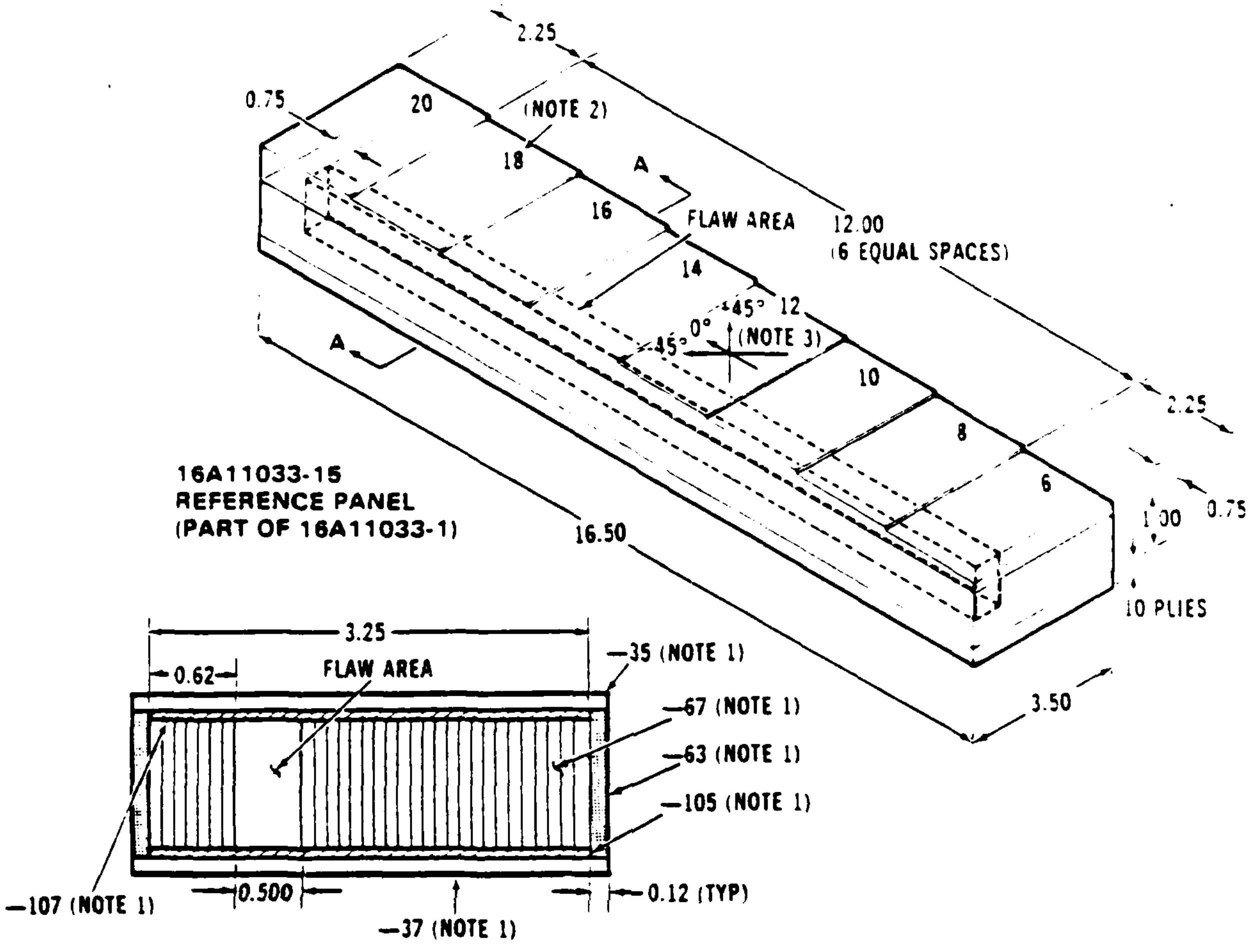


NOTES:

1. Materials: (See table 1-3.)
   —29. FMS-2023. Type 3 or Type 5. Form A or Form C graphite-epoxy tape and P5284-3 cloth (1 ply-upper surface)
   —31. FMS-2023. Type 3 or Type 5. Form A or Form C graphite-epoxy tape and P5362-1 cloth (1 ply-lower surface)
   —103. FMS-3018. Form IB adhesive
2. Ply designation indicates thickness of step.
3. Every 4 plies of —29 and —31 graphite-epoxy are oriented -45°, +45°, +45° and -45. This pattern is repeated two times for —31 base and one, two, and three times respectively, for —29 cap 4, 8, and 12 ply thickness.
4. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
5. After cure, drill flat bottom holes to adhesive bond line as shown.
6. Finish: two coats epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-82386), except holes which are unfinished.

NOT 15 0818

Figure 16A11033-13 Graphite-Graphite Reference Part



SECTION A-A

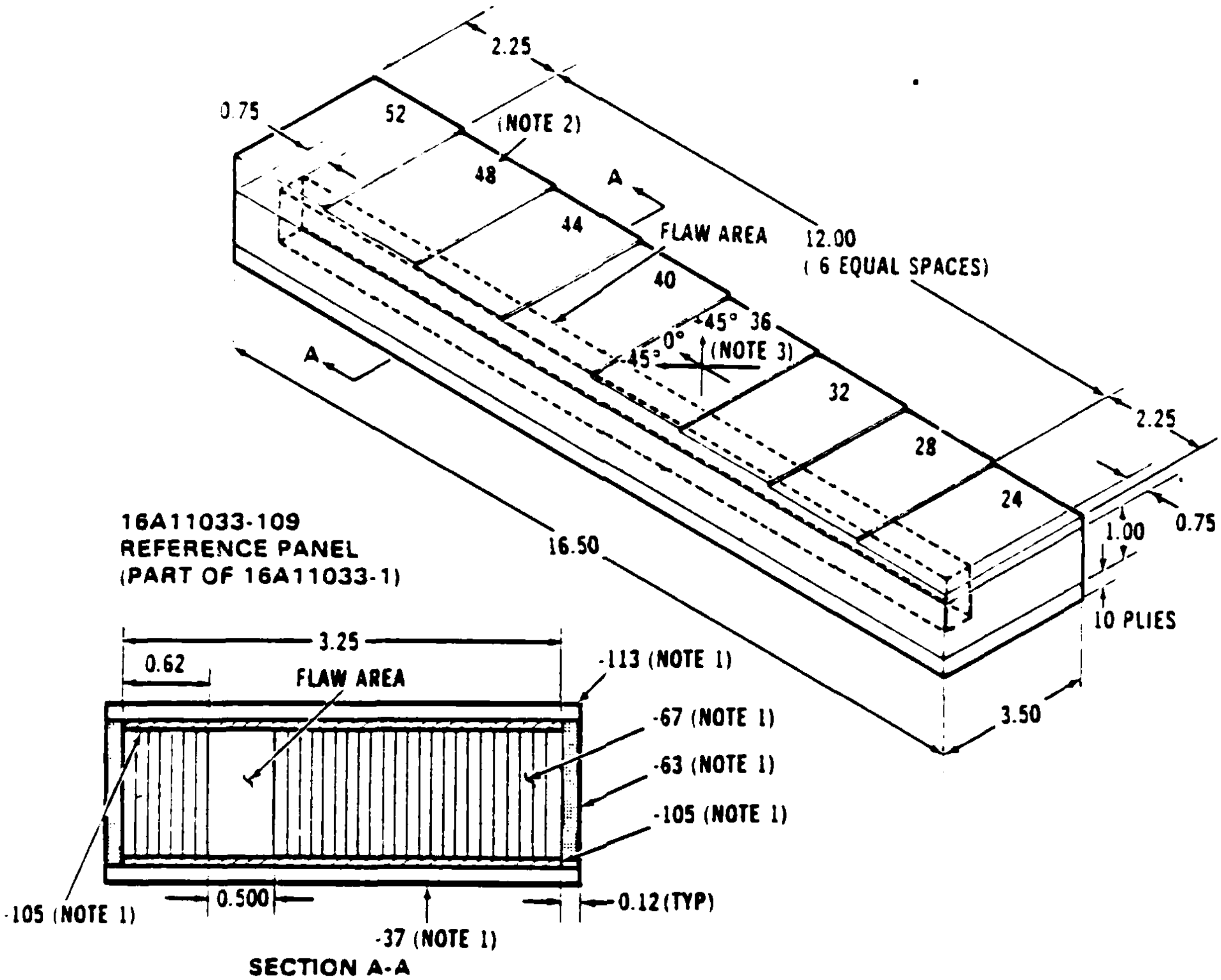
NOTES:

1. Materials: (See table 1-3.)
   - —35/—37. FMS-2023, Type 3 or Type 5, Form A or Form C graphite-epoxy tape, P5284-3 cloth (1 ply-inner surface), and P5362-1 cloth (1 ply-outer surface)
   - —63. FMS-1044, Type V sealant
   - —67. P190-1B (5052-1B) aluminum core
   - —105/—107. FMS-3018, Form IB adhesive
2. Ply designation indicates thickness of step.
3. *Orientation of each ply of graphite-epoxy is as follows (where + is +45°, - is -45°, and 0 is 0°)*

—35 ply 1-6	+-+-+-	ply 13-14	-+
ply 7-8	+-	ply 15-16	-+
ply 9-10	+-	ply 17-18	-+
ply 11-12	-+	ply 19-20	-+
—37 ply 1-10	+--+0 0+--+		

4. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance
5. Install flaw area as follows
   a. Cut plug from core
   b. Assemble core to stepped top. Lay strip of teflon sheet in plug cut out area of core and reinstall plug in core. Cover core surface with teflon sheet. Bond assembly
   c. Remove teflon sheet, plug, and teflon strip and discard
   d. Bond bottom skin
   e. *Seal exposed areas of core with sealant*
6. Finish: two coats epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286).

Figure 16A11033-15 Graphite-Core Reference Part



NOTES.

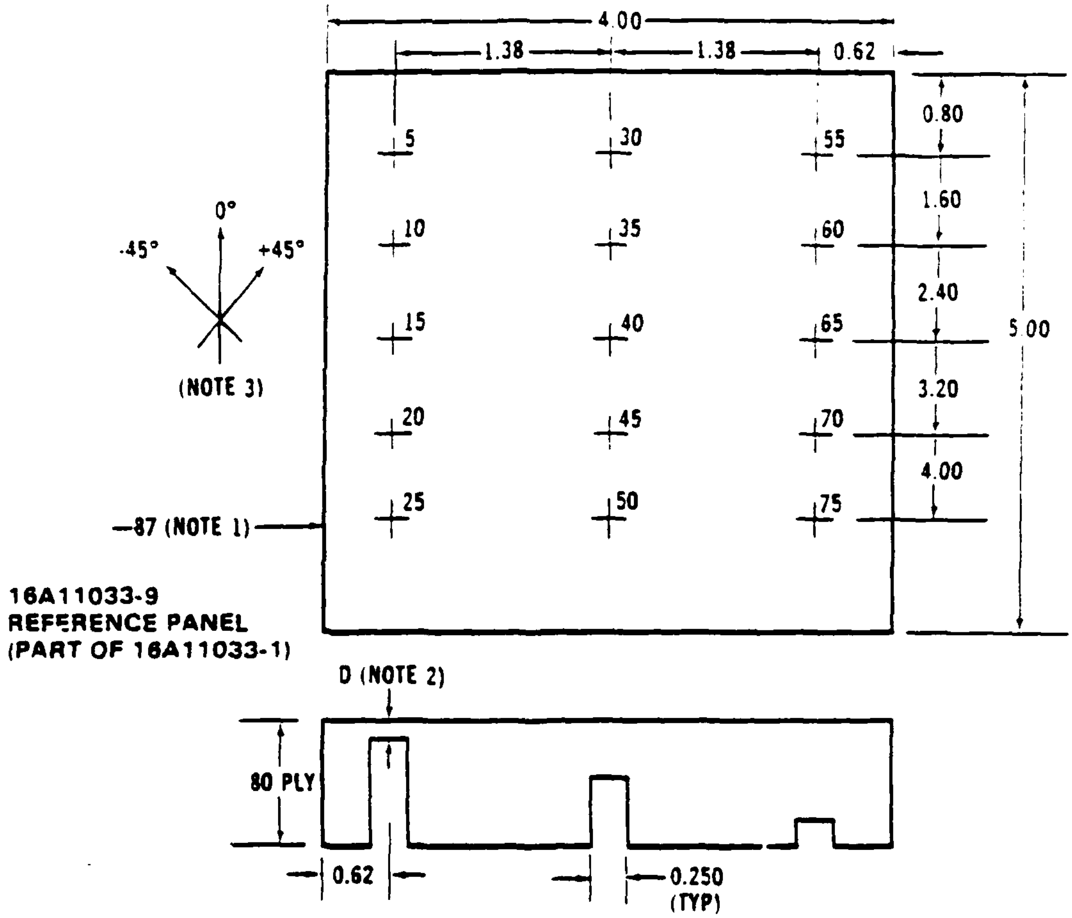
1. Materials (See table 1-3.)
   - -37 - -113. FMS-2023, Type 3 or Type 5, Form A or Form C graphite-epoxy tape. P5284-3 cloth (1 ply-inner surface), and P5362-1 cloth (1 ply-outer surface)
   - -63. FMS-1044, Type V sealant
   - -67. P190-18 (5052-18) aluminum core
   - -105. FMS-3018, Form IB adhesive
2. Ply designation indicates thickness of step.
3. Orientation of each ply of graphite-epoxy is as follows (where + is 45°, - is -45°, and 0 is 0°):

-113	ply 1-12	+-+-+-+-+-+-
	ply 13-24	-+-+-+-+-+-+
	ply 25-28	+--+
	ply 29-32	+--+
	ply 33-36	+--+
	ply 37-40	+--+
	ply 41-44	+--+
	ply 45-48	+--+
	ply 49-52	+--+
-37	ply 1-10	+--+ 00 +--+

4. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
5. Install flaw area as follows:
   a. Cut plug from core.
   b. Assemble core to stepped top. Lay strip of teflon sheet in plug cut out area of core and reinstall plug in core. Cover core surface with teflon sheet. Bond assembly.
   c. Remove teflon sheet, plug, and teflon strip and discard.
   d. Bond bottom skin.
   e. Seal exposed areas of core with sealant.
6. Finish: two coats epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286).

NOT

Figure 16A11033-109 Graphite-Core Reference Part



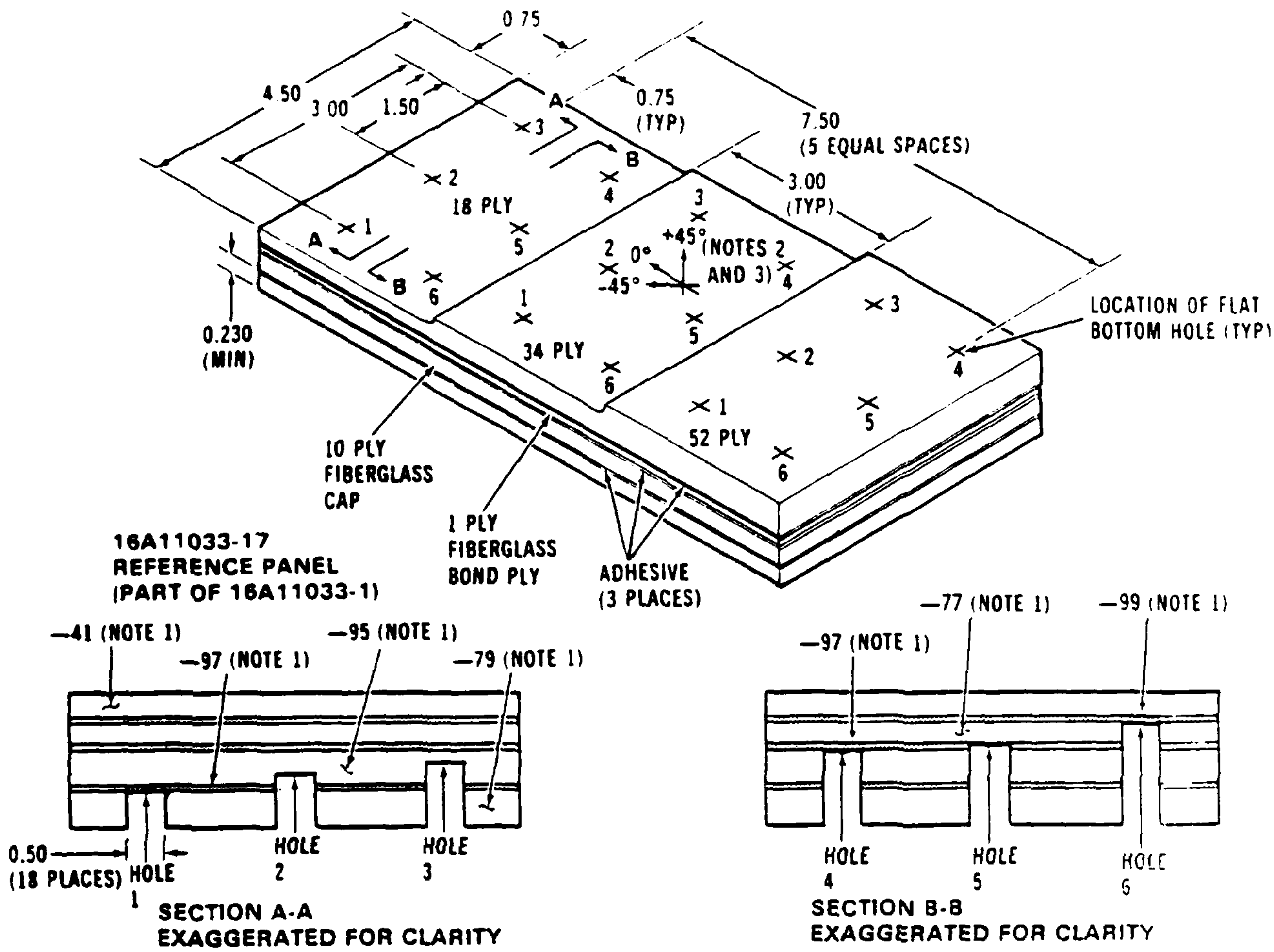
NOTES:

1. Material: (See table 1-3.) - 87, FMS-2023, Type 3 or Type 5, Form A or Form C graphite-epoxy tape and P5284-3 cloth (1 ply-upper surface).
2. Ply designation indicates depth to hole.

PLY	D(± 0.0010)	PLY	D(± 0.0010)
5	0.0315	45	0.2515
10	0.0590	50	0.2790
15	0.0865	55	0.3065
20	0.1140	60	0.3340
25	0.1415	65	0.3615
30	0.1690	70	0.3890
35	0.1965	75	0.4165
40	0.2240		

3. Every 5 plies of graphite-epoxy are oriented +45°, −45°, 0°, −45° and +45°. This pattern is repeated 16 times for a total of 80 plies.
4. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
5. After cure, drill flat bottom holes to depths given in note 2.
6. Finish: two coats MIL-P-23377 epoxy primer and two coats MIL-C-83286 urethane coating, except holes which are unfinished.

Figure 16A11033-9 High Resolution Reference Part



NOTES:

1. Materials: (See table 1-3.)
   - —41, FMS-2023, Type 3 or Type 5, Form A or Form C graphite-epoxy tape and P5284-3 cloth (1 ply-upper surface)
   - —77, P5284-5, Style 181 glass fabric
   - —79, Type 1, Composition B titanium (Military Specification MIL-T-9046)
   - —95, FMS-1023, Class 2, Type A fiberglass
   - —97, FMS-3018, Form IB adhesive
   - —99, FMS-3011 adhesive
2. Orientation of graphite-epoxy plies is as follows (where + is 45°, - is -45°, and 0 is 0°):

ply 1-6	+-0+-0
ply 7-12	+-0+-0
ply 13-18	+-0+-0
ply 19-26	+-0+-+-+
ply 27-34	--+--0-+
ply 35-40	0-+0-+
ply 41-46	0-+0-+
ply 47-52	0-+0-+

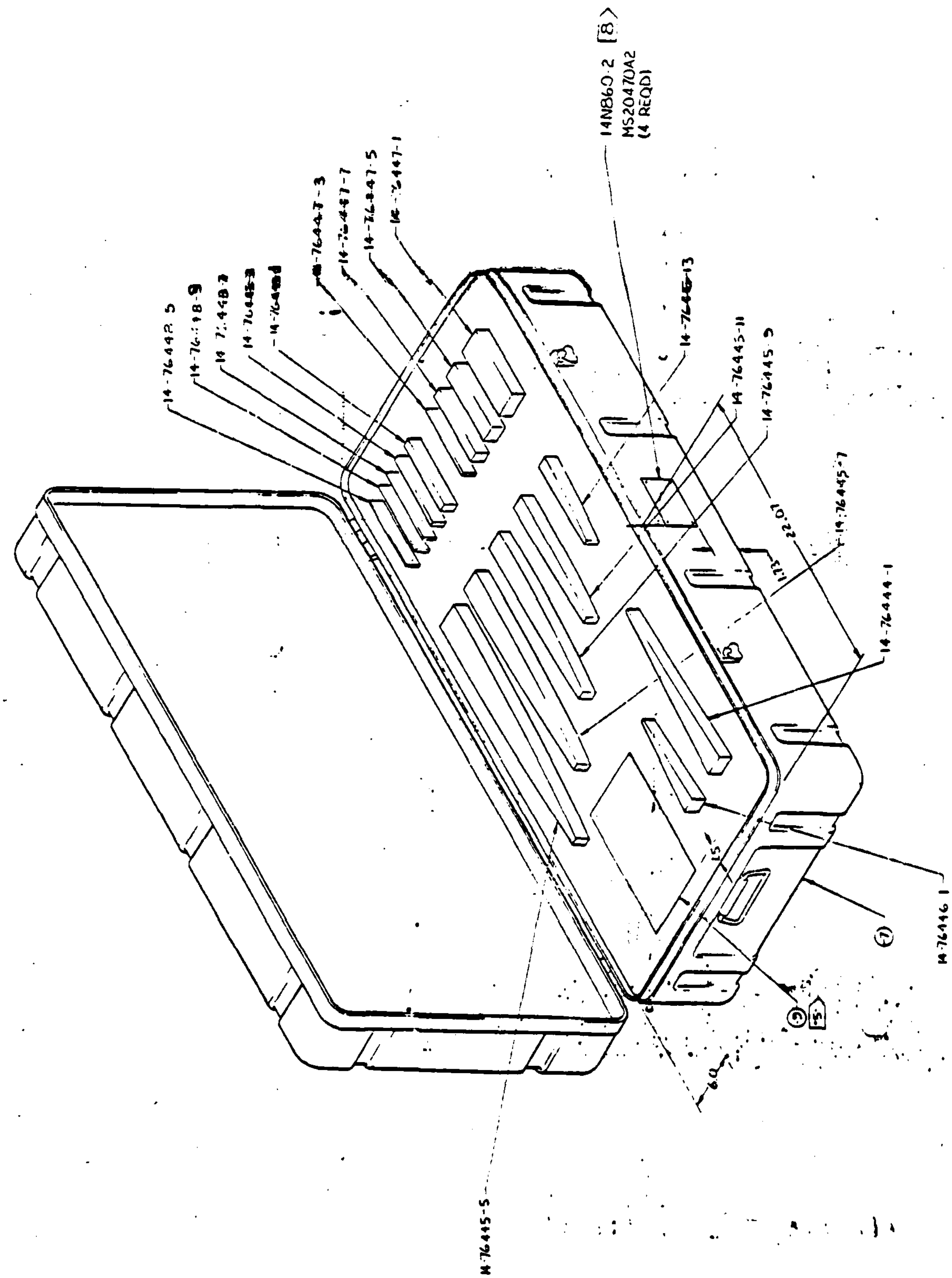
3. Orientation of each ply of fiberglass is 90° to adjacent plies, e.g., +45°, -45°, +45°, -45°, etc.
4. Dimensions with two digits after the decimal point uses ± 0.03 tolerance while three digits after the decimal point uses ± 0.010 tolerance.
5. After cure, drill flat bottom holes as follows
   - *Hole 1 to surface of —97 as shown*
   - Hole 2 to 4th ply in —95 as shown
   - Hole 3 to 8th ply in —95 as shown
   - *Hole 4 to surface of —97 as shown*
   - Hole 5 to surface of —77 as shown
   - Hole 6 to surface of —99 as shown
6. Finish:
   a. Composite and laminate—two coats epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286), except holes which are unfinished.
   b. Metallic—one coat epoxy primer (Military Specification MIL-P-23377) and two coats urethane coating (Military Specification MIL-C-83286), except holes which are unfinished.

NDT 16 2208

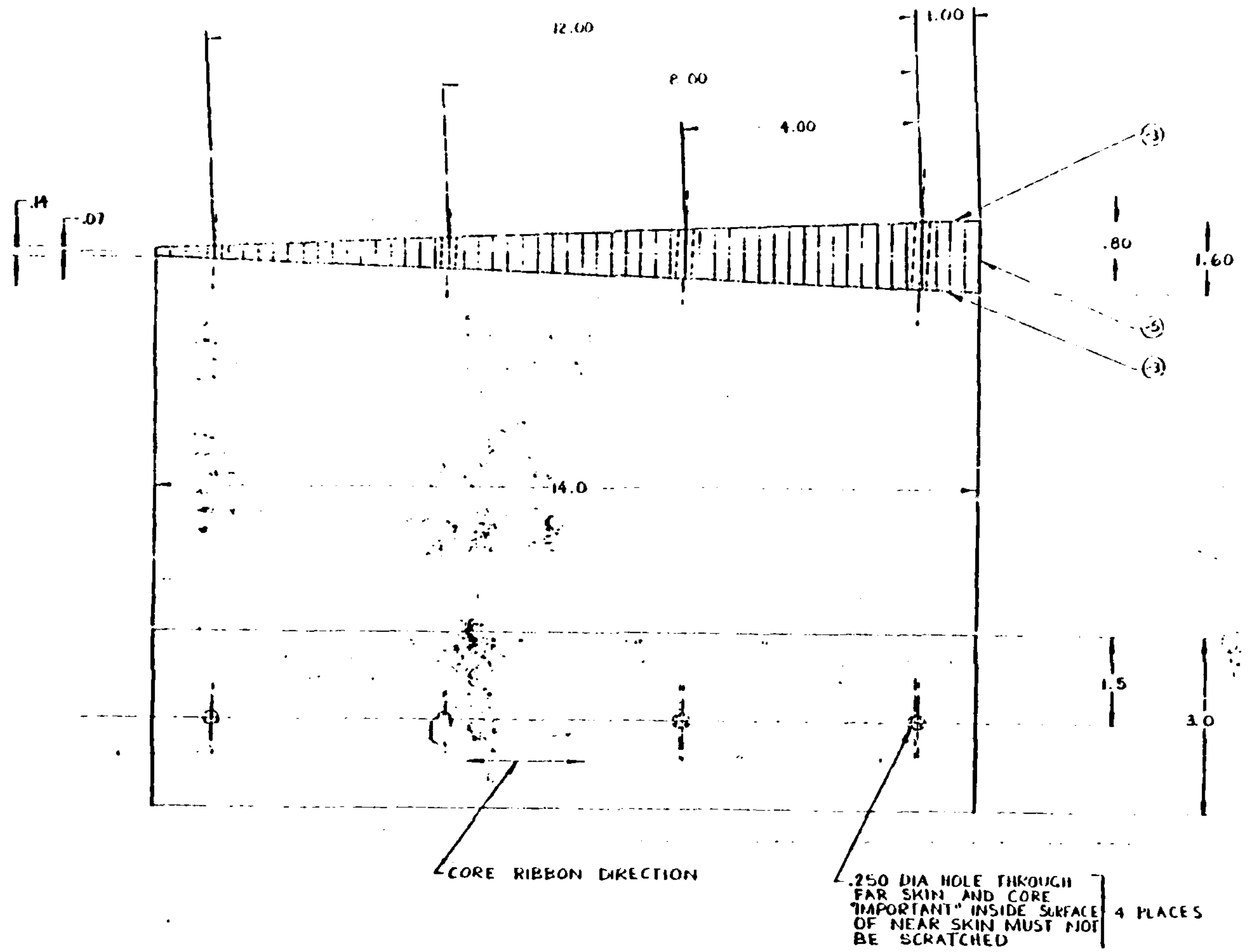
Figure 16A11033-17 Graphite-Titanium Reference Part

APPENDIX D

DESCRIPTION OF F-5 HONEYCOMB STRUCTURE SAMPLES (FROM A COPY OF THE ENGINEERING DRAWINGS OF THE SAMPLES)



14N860-2 8
MS20470A2
(4 REQD)
14-76445-13
14-76445-11
14-76445-9
14-76445-7
14-76444-1
14-76447-1
14-76447-5
14-76447-7
14-76446-1
14-76445-5
22.07
1.73
6.0
.15



6 PART PROTECTION PER MATERIALS HANDLING MANUAL SPEC P-6950

5 USE PROCESS SPEC MA122

4 USE IM-23 TYPE II

3 FINISH OUTSIDE OF SKINS ONLY OF BONDED ASSEMBLY PER STF0117

2 BOND PER PROCESS SPEC MA-108 EXCEPT DO NOT SEAL HOLES AND CORE EDGES PER MA-14

1 USE 2.3-1/4-10N (5052)E PER NAE-171 CLASS I

NOTES

QTY REQD			-1	PART OR IDENTIFYING NO.	SEE NOTES	NOMENCLATURE OR DESCRIPTION	MATERIAL OR CODE IDENT NO.	SIZE	SPECIFICATION OR PROCUREMENT DATA	ZONE	ITEM
											3
			1	-5	1	CORE	AL FOIL HONEYCOMB	L60-H.1 ±.1		5	2
			2	-3		SKIN	SHEET AL 7075-T6	.06-H.1 ±.3 I	QQ-A-250/12	5	1

PARTS LIST

UNLESS OTHERWISE NOTED
LINEAR TOLERANCES .X = ±.1, .XX = ±.04, .XXX = ±.010
LINEAR DIM ARE IN INCHES
ANGULAR TOL EXCEPT SHEET METAL FLG ± 0° 30'
MFG ACCEPTANCE TOL PER 10Y201
FINISH PER NOTED
ODD DASH NO SHOWN EVEN DASH NO OPPOSITE
FOR USAGE DATA SEE APPLICATION LIST

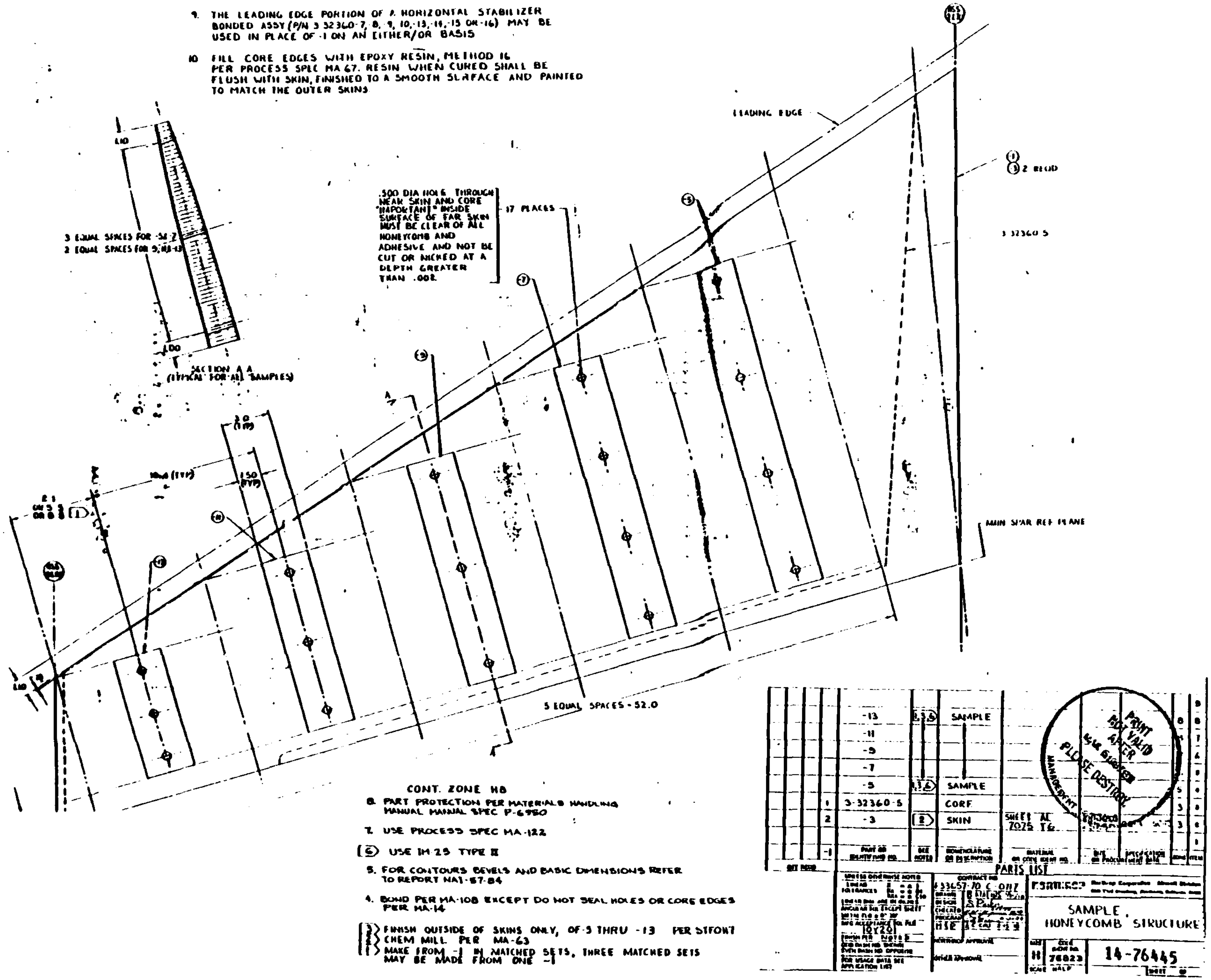
CONTRACT NO. F33657-70-C-0717
DRAWN B. NALINS
DESIGN
CHECKED
PROGRAM
MFP
NORTHROP APPROVAL
OTHER APPROVAL

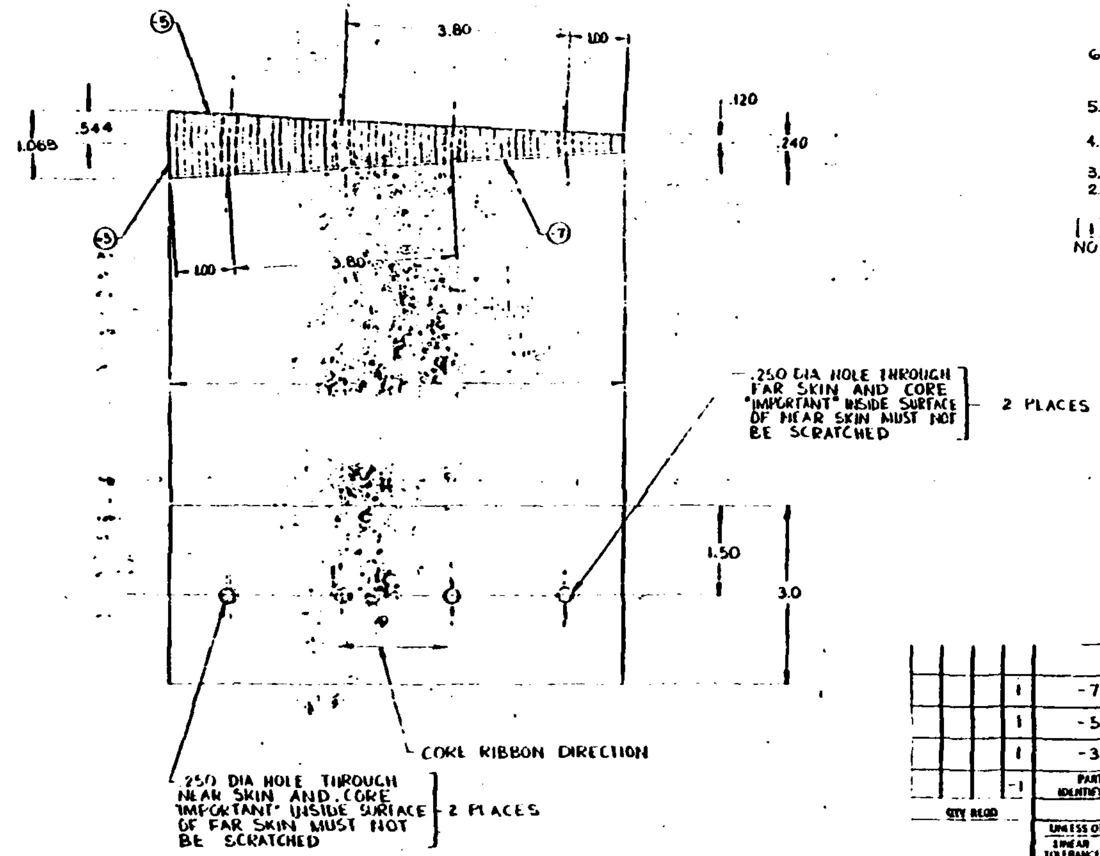
NORTHROP Northrop Corporation Aircraft Division

SAMPLE HONEYCOMB STRUCTURE

SIZE H | CODE IDENT No. 76823 | 14-76444

SCALE FULL | SHEET OF


9. THE LEADING EDGE PORTION OF A HORIZONTAL STABILIZER BONDED ASSY (P/N 3-32360-7, 8, 9, 10, 13, 11, 15 OR 16) MAY BE USED IN PLACE OF -1 ON AN EITHER/OR BASIS
10 FILL CORE EDGES WITH EPOXY RESIN, METHOD 16 PER PROCESS SPEC MA 67. RESIN WHEN CURED SHALL BE FLUSH WITH SKIN, FINISHED TO A SMOOTH SURFACE AND PAINTED TO MATCH THE OUTER SKINS
LEADING EDGE
2 REQD
3-32360-5
.500 DIA HOLE THROUGH NEAR SKIN AND CORE "IMPORTANT" INSIDE SURFACE OF FAR SKIN MUST BE CLEAR OF ALL HONEYCOMB AND ADHESIVE AND NOT BE CUT OR NICKED AT A DEPTH GREATER THAN .002
17 PLACES
3 EQUAL SPACES FOR -5,-7
2 EQUAL SPACES FOR -9,-11,-13
SECTION A-A
(TYPICAL FOR ALL SAMPLES)
MAIN SPAR REF PLANE
5 EQUAL SPACES - 52.0
CONT. ZONE H8
8. PART PROTECTION PER MATERIALS HANDLING MANUAL SPEC P-6950
7. USE PROCESS SPEC MA-122
6 USE IM 25 TYPE II
5. FOR CONTOURS BEVELS AND BASIC DIMENSIONS REFER TO REPORT NAI-67-84
4. BOND PER MA-108 EXCEPT DO NOT SEAL HOLES OR CORE EDGES PER MA-14
3 FINISH OUTSIDE OF SKINS ONLY, OF -5 THRU -13 PER STFONT
2 CHEM MILL PER MA-63
1 MAKE FROM -1 IN MATCHED SETS, THREE MATCHED SETS MAY BE MADE FROM ONE -1
-13 SAMPLE
-11
-9
-7
-5 SAMPLE
3-32360-5 CORE
-3 SKIN
SHEET AL 7075 T6
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
PARTS LIST
PRINT NOT VALID AFTER
PLEASE DESTROY
MANAGEMENT
F33657-70-C-0117
SAMPLE, HONEYCOMB STRUCTURE
H 76823 14-76445



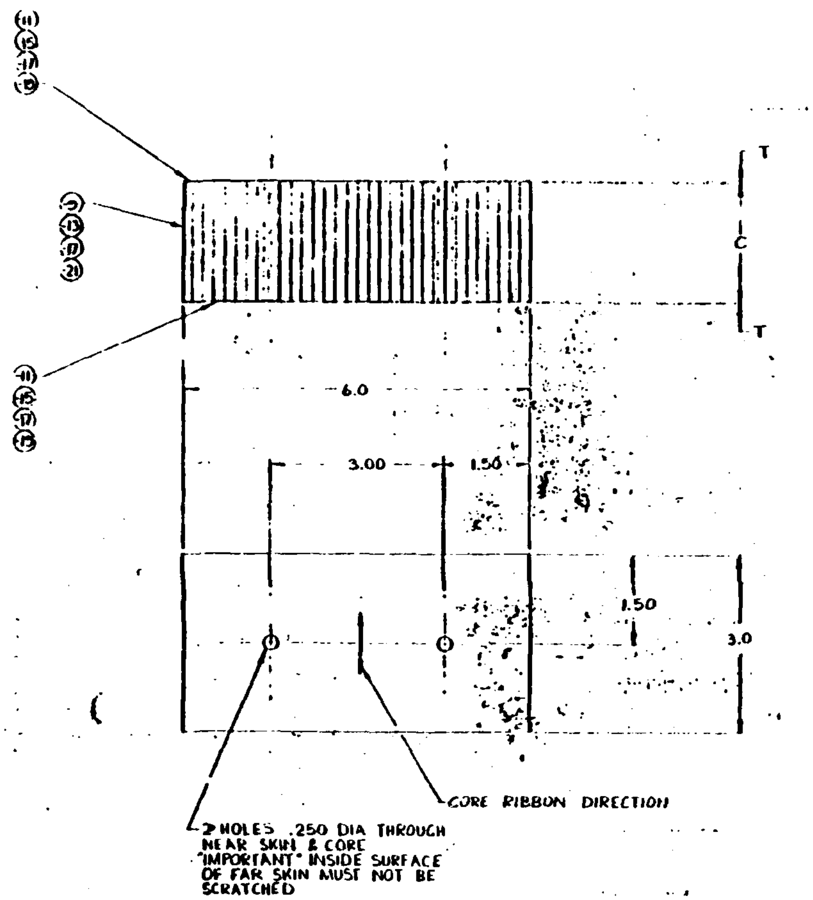
6. PART PROTECTION PER MATERIALS HANDLING MANUAL SPEC P-6950
5. USE PS MA 122
4. USE IM-23 TYPE II
3. FINISH OUTSIDE OF SKINS ONLY OF BONDED ASSEMBLY PER STF0117
2. BOND PER PROCESS SPEC MA-10B EXCEPT DO NOT SEAL HOLES AND CORE EDGES PER MA-14
(1) USE 3.1-1/8-07N (5052)E PER NAI-1111 CLASS I

NOTES

QTY REQD		PART OR IDENTIFYING NO.	SEE NOTES	NOMENCLATURE OR DESCRIPTION	MATERIAL OR CODE IDENT NO.	SIZE OR PROCUREMENT DATA	SPECIFICATION	ZONE	ITEM
									4
	1	-7		SKIN	SHEET, AL 7075-T6	.050 x 3.1 x 7.8	QQ-A-250/12	7	3
	1	-5		SKIN	SHEET, AL 7075-T6	.020 x 3.1 x 7.8	QQ-A-250/12	6	2
	1	-3	(1)	CORE	AL FOIL HONEYCOMB	1.2 x 3.1 x 7.8		8	1
	-1								

PARTS LIST

UNLESS OTHERWISE NOTED LINEAR TOLERANCES .X = ± .1 .XX = ± .04 .XXX = ± .010 LINEAR DIM ARE IN INCHES ANGULAR TOL EXCEPT SHEET METAL FLG ± 0° 30' MFG ACCEPTANCE TOL PER 10Y201 FINISH PER NOTED ODD DASH NO SHOWN EVEN DASH NO OPPOSITE FOR USAGE DATA SEE APPLICATION LIST	CONTRACT NO. F33657-70-C-0117 DRAWN P. MATLINS DESIGN S. BARKIN CHECKED PROGRAM MTD NORTHROP APPROVAL OTHER APPROVAL	NORTHROP Northrop Corporation Aircraft Division SAMPLE, HONEYCOMB STRUCTURE	SIZE H CODE IDENT NO. 76823 14-76446 SCALE FULL SHEET OF



DA -1	C	T
-1	2.000	.016
-3	.250	.025
-5	1.443	.032
-7	.750	.020

NOTES:

1 CORE TO CONFORM TO NAI-1171 CLASS I, USE .001N FOIL .125 CELL (4.5#/FT³ DENSITY) 5052-H39 ALUM ALLOY MATERIAL PER QQ-A-250/8

2 USE IM-23 TYPE II

3 CORE TO CONFORM TO NAI-1171 CLASS I, USE .0015N FOIL .125 CELL (6.1#/FT³ DENSITY) 5052-H39 ALUM ALLOY MATERIAL PER QQ-A-250/8

4 CORE TO CONFORM TO NAI-1171 CLASS I, USE .001N FOIL .187 CELL (3.1#/FT³ DENSITY) 5052-H39 ALUM ALLOY MATERIAL PER QQ-A-250/8

5 CORE TO CONFORM TO NAI-1397 TYPE 5052 F40-.002 (3.1#/FT³ DENSITY)

6 BOND PER MA-108 EXCEPT DO NOT SEAL HOLES OR CORE EDGES PER MA-14

7 FINISH OUTSIDE OF SKINS ONLY OF BONDED ASSEMBLY PER STFO 117

8 USE PROCESS SPEC MA-122

9 PART PROTECTION PER MATERIALS HANDLING MANUAL SPEC P-6950

PARTS LIST

-7	-5	-3	-1	PART OR IDENTIFYING NO.	SEE NOTES	NOMENCLATURE OR DESCRIPTION	MATERIAL OR CODE IDENT NO.	SIZE OR PROCUREMENT DATA	SPECIFICATION	ZONE	ITEM
2				-23		SKIN	SHEET AL 7075-T6	.020 x 3.1 x 6.1	QQ-A-250/12	8	8
1				-21	5	CORE	AL FOIL HONEYCOMB	.750 x 3.1 x 6.1		8	7
	2			-19		SKIN	SHEET AL 2024-T3	.032 x 3.1 x 6.1	QQ-A-250/4	8	6
	1			-17	4	CORE	AL FOIL HONEYCOMB	1.443 x 3.1 x 6.1		8	5
		2		-15		SKIN	SHEET AL 7075-T6	.025 x 3.1 x 6.1	QQ-A-250/12	8	4
		1		-13	3	CORE	AL FOIL HONEYCOMB	.250 x 3.1 x 6.1		8	3
			2	-11		SKIN	SHEET AL 7075-T6	.016 x 3.1 x 6.1	QQ-A-250/12	8	2
			1	-9	1	CORE	AL FOIL HONEYCOMB	2.000 x 3.1 x 6.1		8	1

QTY REQD

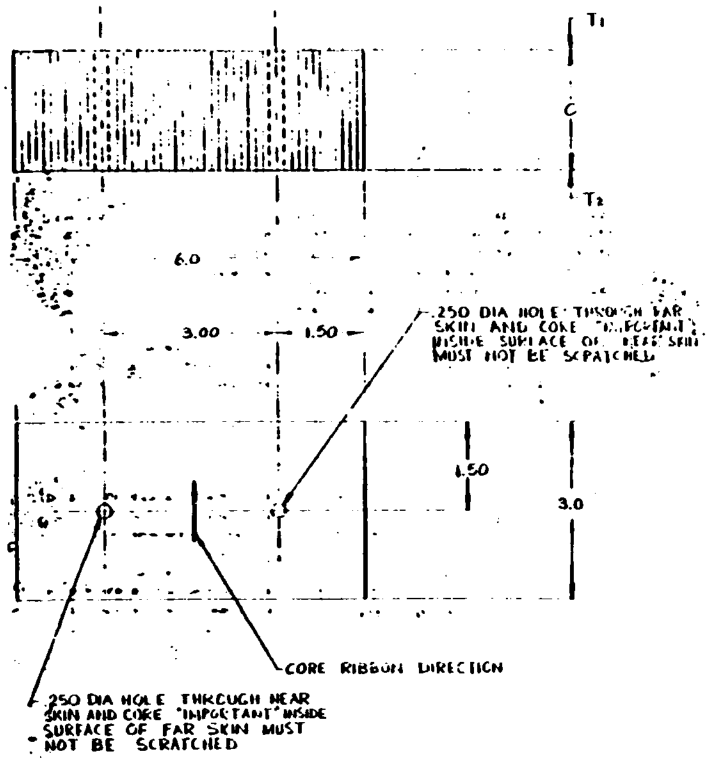
UNLESS OTHERWISE NOTED
LINEAR TOLERANCES .X = ±.1, .XX = ±.03, .XXX = ±.010
LINEAR DIM ARE IN INCHES
ANGULAR TOL EXCEPT SHEET METAL FLG ± 0° 30'
MFG ACCEPTANCE TOL PER 101201
FINISH PER NOTED
ODD DASH NO. SHOWN EVEN DASH NO. OPPOSITE
FOR USAGE DATA SEE APPLICATION LIST

CONTRACT NO. F33657-70-C-0717
DRAWN B MILNS
DESIGN S H
CHECKED
PROGRAM
MTP
NORTHROP APPROVAL
OTHER APPROVAL

NORTHROP Northrop Corporation Aircraft Division

SAMPLE, HONEYCOMB STRUCTURE

SIZE H | CODE IDENT NO. 76323 | 14-76447
SCALE FULL | SHEET OF



	C	T1	T2
-1	.6[illegible]0	.0[illegible]0	.03[illegible]
-3	.500	.150	.020
-5	.165	.110	.060
-7	.250	.050	.025
-9	.187	.032	.025

9 PART PROTECTION PER MATERIALS HANDLING MANUAL SPEC P-6950

8 MACHINE PER MA-124 OR CHEM MILL PER MA-65 TO 0.110 ±.003

7 USE PROCESS SPEC MA-122

6 USE MA-23 TYPE II

5 FINISH OUTSIDE OF SKINS ONLY OF BONDED ASSEMBLY PER STF0117

4 BOND PER MA-105 EXCEPT DO NOT SEAL HOLES OR CORE EDGES PER MA-14

3 USE TYPE 8-4.0 CLASS I GRADE A PER NAI-1340

2 USE 4.5-1/8-10N PER NAI-1171 CLASS I

1 USE 6.1-1/8-15N PER NAI 1171 CLASS I

-9	-7	-5	-3	-1	PART OR IDENTIFYING NO.	SEE NOTES	NOMENCLATURE OR DESCRIPTION	MATERIAL OR CODE IDENT NO.	SIZE	SPECIFICATION OR PROCUREMENT DATA	ZONE	ITEM
1					-33	3	CORE	NYLON FIBER/PHENOLIC HONEYCOMB	.187 x 3.1 x 6.1			12
1	1				-31		SKIN	SHEET AL 7075-	.025 x 3.1 x 6.1	QQ-A-250/12		11
	1				-29		SKIN	SHEET AL 7075-T6	.050 x 3.1 x 6.1	QQ-A-250/12		10
	1				-27	2	CORE	AL FOIL HONEYCOMB	.250 x 3.1 x 6.1			9
		1			-25	8	SKIN	SHEET AL 7075-T6	.125 x 3.1 x 6.1	QQ-A-250/12		8
		1			-23	1	CORE	AL FOIL HONEYCOMB	.165 x 3.1 x 6.1			7
		1	1		-21		SKIN	SHEET AL 7075-T6	[illegible] x 3.1 x 6.1	QQ-A-250/12		6
			1		-19		SKIN	SHEET AL 7075-T6	.150 x 3.1 x 6.1	QQ-A-250/12		5
			1		-17	1	CORE	AL FOIL HONEYCOMB	.500 x 3.1 x 6.1			4
1				1	-15		SKIN	SHEET AL 7075-T6	.032 x 3.1 x 6.1	QQ-A-250/12		3
				1	-13		SKIN	SHEET AL 7075-T6	.040 x 3.1 x 6.1	QQ-A-250/12		2
				1	-11	1	CORE	AL FOIL HONEYCOMB	.65 x 3.1 x 6.1			1

QTY REQD

PARTS LIST

UNLESS OTHERWISE NOTED
LINEAR TOLERANCES .X = ±.1 .XX = ±.04 .XXX = ±.010
LINEAR DIM ARE IN INCHES
ANGULAR TOL EXCEPT SHEET METAL FLG ± 0° 30'
MFG ACCEPTANCE TOL PER 10Y201
FINISH PER NOTED
ODD DASH NO. SHOWN EVEN DASH NO. OPPOSITE
FOR USAGE DATA SEE APPLICATION LIST

CONTRACT NO. F33657-70-C-0717
DRAWN B MAUNS
DESIGN S [illegible]
CHECKED [illegible]
PROGRAM [illegible]
M & P [illegible]
NORTHROP APPROVAL
OTHER APPROVAL

NORTHROP Northrop Corporation Aircraft Division

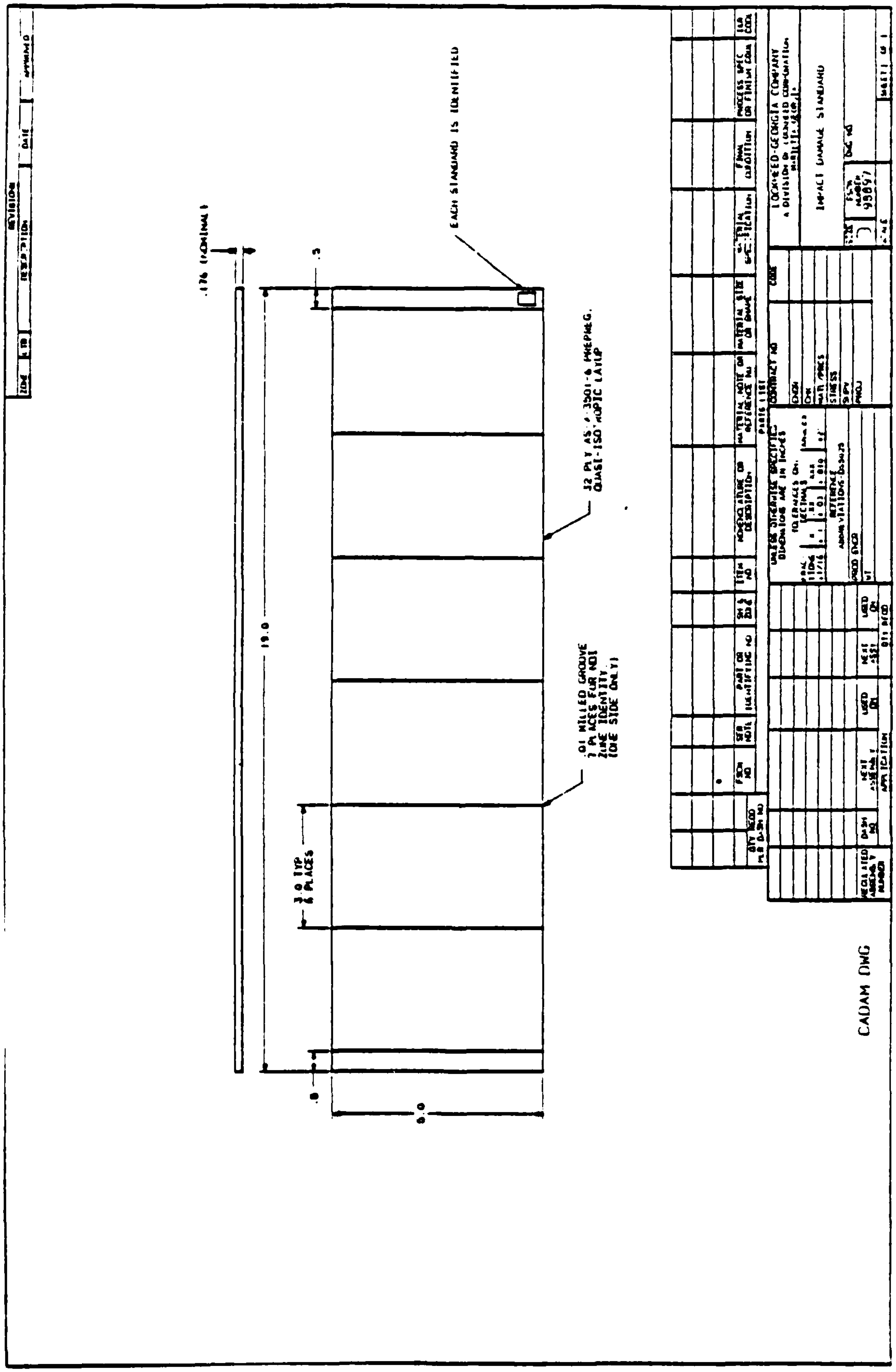
SAMPLE, HONEYCOMB STRUCTURE

SIZE H CODE IDENT NO. 76823 14-76448

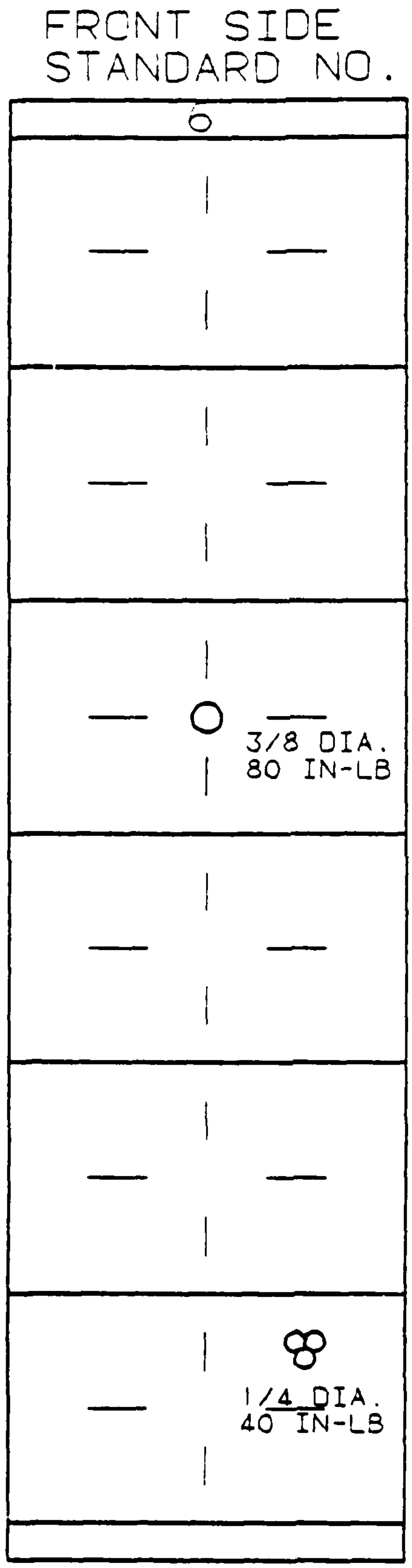
SCALE FULL SHEET OF

APPENDIX E

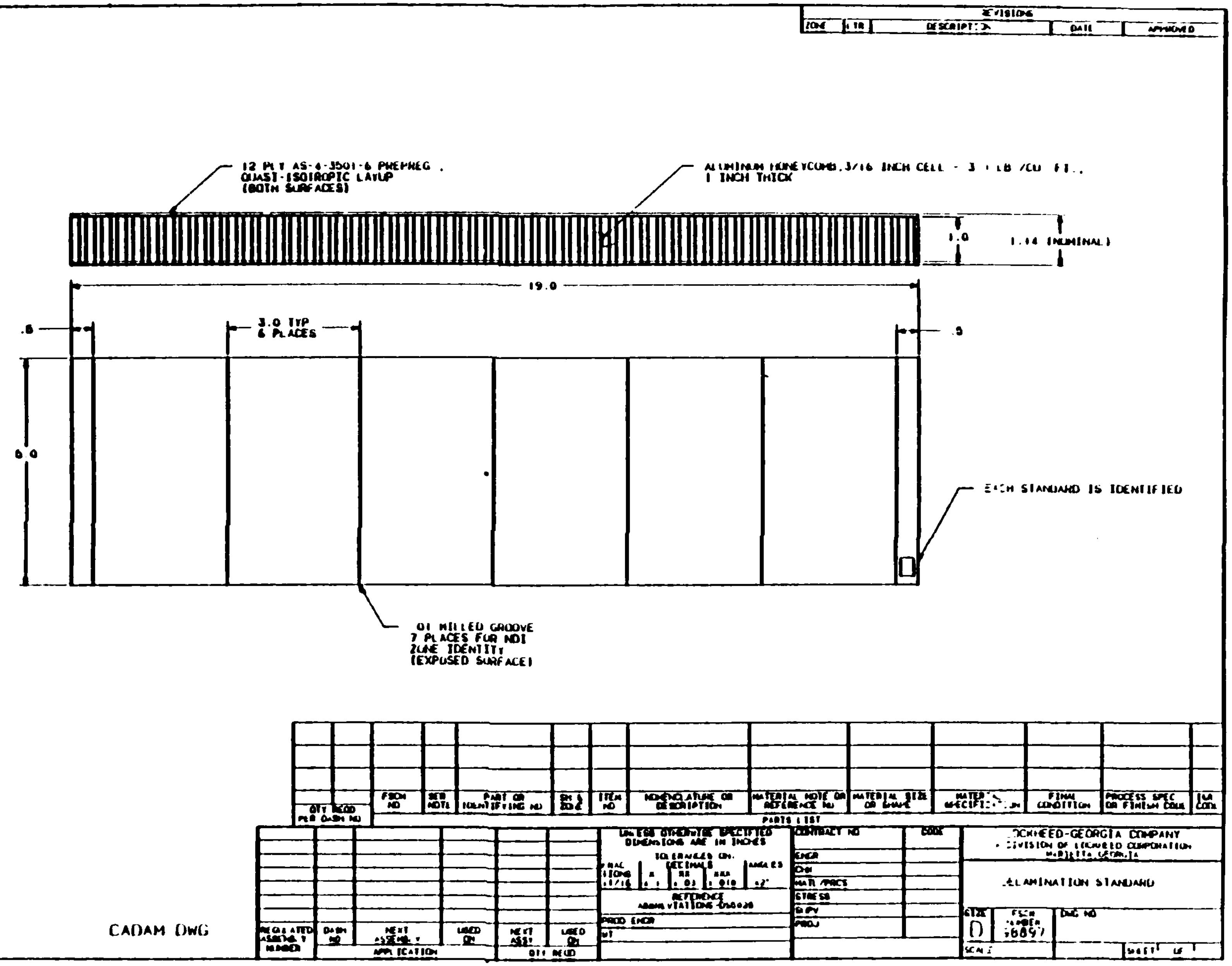
DESCRIPTION OF GRAPHITE/EPOXY SAMPLES
(FROM W. H. SPROAT, "COMPOSITE NDI PROFICIENCY KIT AND METHODOLOGY,
HARDWARE DESIGN AND FABRICATION,"
PRELIMINARY REPORT, LOCKHEED-GEORGIA COMPANY, AUGUST, 1986)



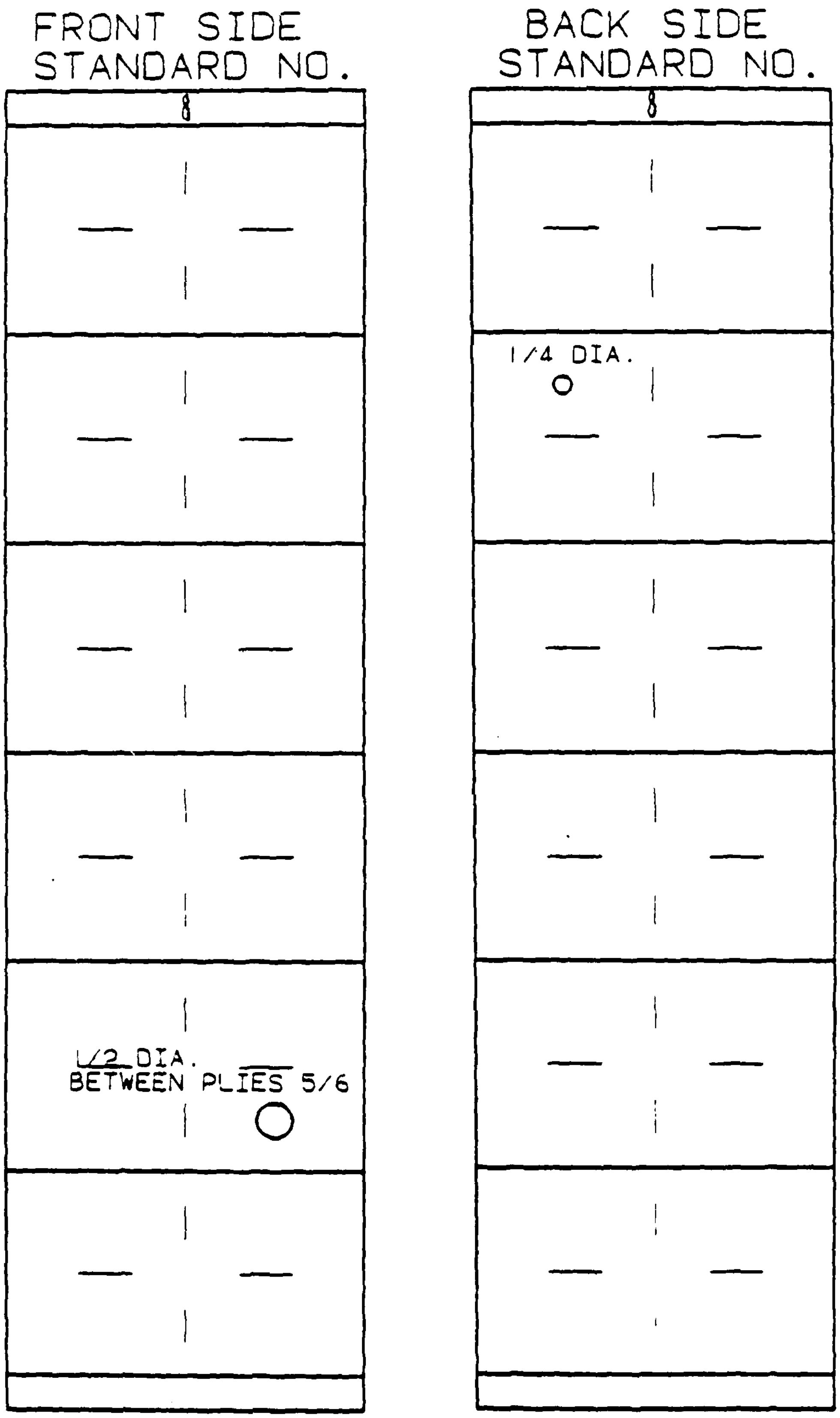
EACH STANDARD IS IDENTIFIED
.176 (NOMINAL)
.5
19.0
32 PLY AS-4/3501-6 PREPREG.
QUASI-ISOTROPIC LAYUP
.01 MILLED GROOVE
7 PLACES FOR NDI
ZONE IDENTITY
(ONE SIDE ONLY)
3.0 TYP
6 PLACES
.8
6.0
REVISIONS
LOCKHEED-GEORGIA COMPANY
IMPACT DAMAGE STANDARD
PARTS LIST
CADAM DWG



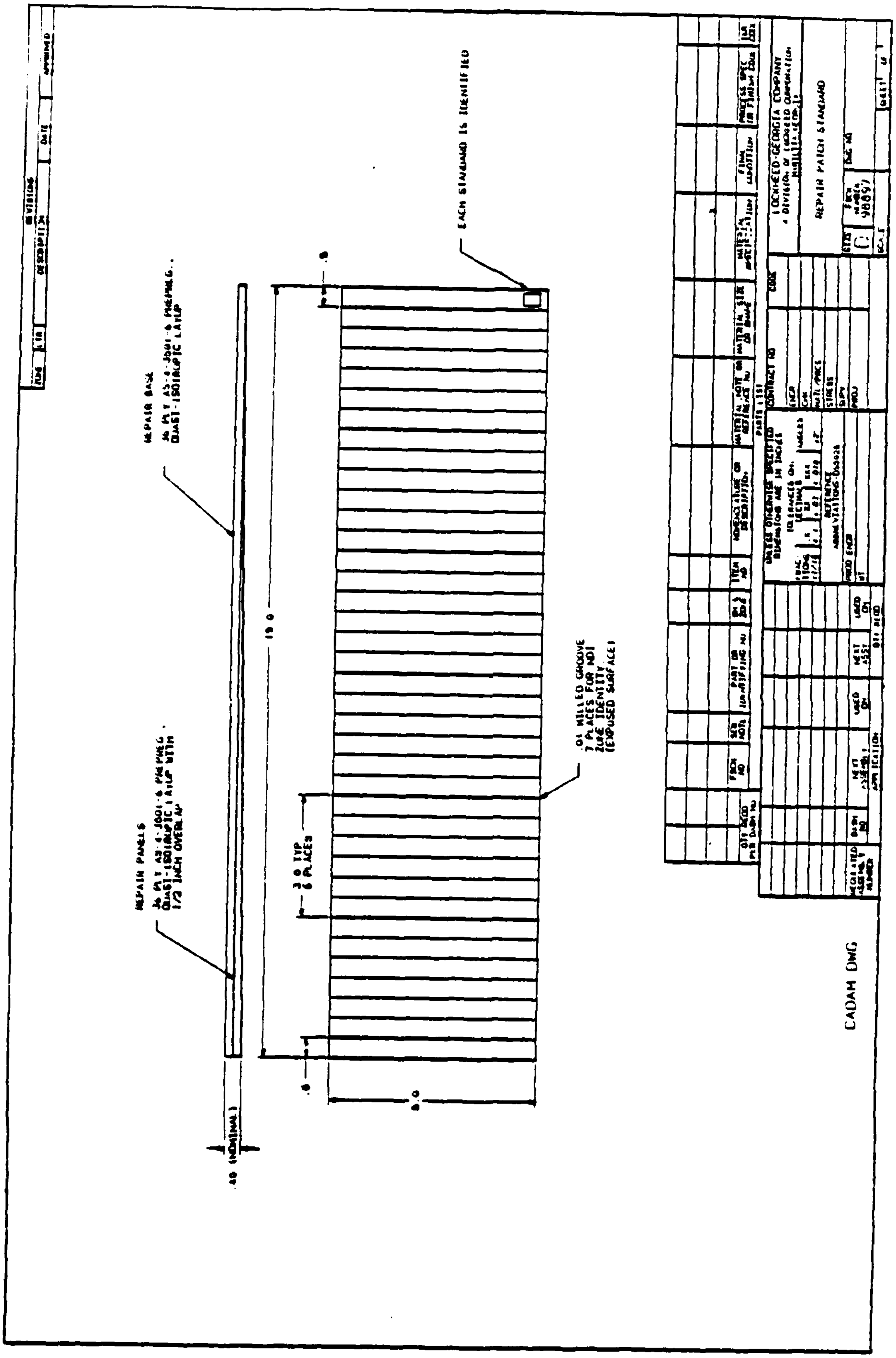
IMPACT DAMAGE ENERGY LEVELS
AND LOCATIONS



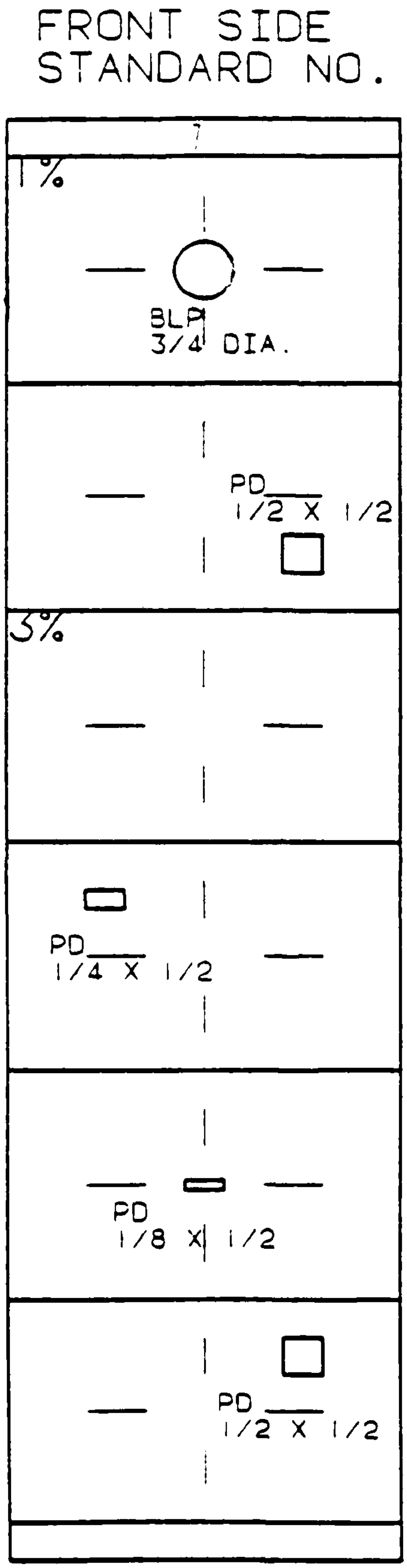
REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
12 PLY AS-4-3501-6 PREPREG, QUASI-ISOTROPIC LAYUP (BOTH SURFACES)
ALUMINUM HONEYCOMB, 3/16 INCH CELL - 3.1 LB/CU FT., 1 INCH THICK
1.0
1.14 (NOMINAL)
19.0
.5
3.0 TYP 6 PLACES
6.0
EACH STANDARD IS IDENTIFIED
.01 MILLED GROOVE 7 PLACES FOR NDI ZONE IDENTITY (EXPOSED SURFACE)
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
LOCKHEED-GEORGIA COMPANY
DELAMINATION STANDARD
CADAM DWG



DELAMINATION ENVELOPE LOCATIONS



REVISIONS
REPAIR BASE
36 PLY AS-4-3501-6 PREPREG, QUASI-ISOTROPIC LAYUP
REPAIR PANELS
36 PLY AS-4-3501-6 PREPREG, QUASI-ISOTROPIC LAYUP WITH 1/2 INCH OVERLAP
EACH STANDARD IS IDENTIFIED
.01 MILLED GROOVE
7 PLACES FOR NDI
ZONE IDENTITY
(EXPOSED SURFACE)
3.0 TYP
6 PLACES
19.0
8.0
.40 (NOMINAL)
LOCKHEED-GEORGIA COMPANY
REPAIR PATCH STANDARD
98897
CADAM DWG



REPAIR PANEL FLAW LOCATIONS

ATE

LMED

-8